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TECHNICAL PROGRESS REPORT NO. 13 OCTOBER-DECEMBER 1995

DE-AC22-92PC92159
CE Inc. Contract 10392

Engineering Development of
Advanced Coal-Fired
Low-Emission Boiler Systems.

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PATENT STATUS

Cleared by Chicago OIPC February 6, 1996.

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APPENDIX A Milestone Schedule Plan/Status Report (DOE Form)

APPENDIX B Technical Paper: "Improving Pulverized Coal Plant Performance"

*conf paper removed for separate
cycling at*

APPENDIX C Technical Paper: "Low-Emission Boiler Systems and Potential Air Toxics Regulations Under the Clean Air Act Amendments of 1990"

EXECUTIVE SUMMARY

INTRODUCTION

The Pittsburgh Energy Technology center of the U.S. Department of Energy (DOE) has contracted with Combustion Engineering, Inc. (ABB CE) to perform work on the "Engineering Development of Advanced Coal-Fired Low-Emission Boiler Systems" Project and has authorized ABB CE to complete Phase I on a cost-reimbursable basis and Phases II and III on a cost-share basis.

The overall objective of the Project is the expedited commercialization of advanced coal-fired low-emission boiler systems. The specified primary objectives are:

	Preferred Performance	Minimum Performance
NO _x Emissions, lb/million Btu	0.10	0.20
*SO ₂ Emissions, lb/million Btu	0.10	0.20
Particulate Emissions, lb/million Btu	0.01	0.015
Net Plant (HHV) Efficiency, %	45	42

*3 lb S/million Btu in the coal

The specific secondary objectives are:

- Improved ash disposability.
- Reduced waste generation.
- Reduced air toxics emissions.

The final deliverables are a design data base that will allow future coal-fired power plants to meet the stated objectives and a preliminary design of a Commercial Generation Unit.

The work in Phase I covered a 24-month period and included system analysis, RD&T Plan formulation, component definition, and preliminary Commercial Generating Unit (CGU) design.

Phase II will cover a 24-month period and will include preliminary Proof-of-Concept Test Facility (POCTF) design and subsystem testing.

Phase III will cover a 6-month period and will produce a revised CGU design and a revised POCTF design, cost estimate and a test plan.

Phase IV, the final Phase, will cover a 36-month period and will include POCTF detailed design, construction, testing, and evaluation.

The project will be managed by ABB CE as the contractor and the work will be accomplished and/or guided by this contractor and the following team members.

- DOE Contracting Officer's Representative (COR)
- ABB Combustion Engineering Systems (ABB ES)
- ABB Environment Systems, Inc. (ABBES)
- Raytheon Engineers and Constructors, Inc. (RE&C)
- Dr. Janos Beér, MIT and Dr. Jon McGowan, U. of Mass.
- Association of Edison Illuminating Companies - Power Generation Committee (AEIC)
- Advanced Energy Systems Corporation (AES)
- Black Beauty Coal Company
- Electric Power Research Institute (EPRI)
- Illinois Clean Coal Institute (ICCI)
- Peridot Chemicals, Inc.
- Richmond Power & Light (RP&L)
- Southern Company Services, Inc. (SCS)

SUMMARY

The Project is under budget and generally on schedule. The current status is shown in the Milestone Schedule Status Report included as Appendix A. Task 7 - Component Development and Optimization and, Task 11 - Subsystem Test Operation and evaluation are shown to be slightly behind schedule. Also, addition of Kalina technology may delay completion of Task 8. However, Phase II will be completed on schedule.

Technology Transfer activities included delivering a technical paper to the 1995 International Joint Power Generation Conference as part of a Combustion 2000 Technical Session and commitments for four technical papers in 1996.

Task 7 activities in support of the low-NO_x firing system development were completed. A report on air toxics was written (Appendix C). The CeraMem filter test is still on hold awaiting a decision by Ohio Edison to host the tests.

In Task 8 integrating and optimizing the performance and design of the boiler, turbine and heat exchangers of the Kalina cycle is proceeding but it has required much more time than anticipated. The effort was further complicated by the need to fit equipment into an existing facility while maximizing the use of existing infrastructure. The design of the existing turbine pedestal and the sensitivity of Kalina cycle efficiency to (the existing) cooling tower performance are examples. The net result is that preparation of the preliminary POCTF design will require two to three months more time than was originally estimated. Fortunately, this change fits the new Phase II/Phase III schedule.

The PSD permit application was brought to a point of 80-90% completion, and the application for the state construction permit as completed for RP&L signature. An addendum for the DOE Technical Questionnaire, incorporating the Kalina cycle aspects of the project, was also prepared.

The test designs and plan created in Task 9 were previously submitted and approved, although the plan for the 5,000 acfm CeraMem filter test will be updated following completion of the 200 acfm test.

Task 10 work is nearly complete. Preparation for the second series of combustion tests in the Boiler Simulation Facility (BSF) was completed. The test rig for the 5,000 acfm CeraMem test has been shipped to the fabricator's shop, inspected, cleaned and placed on hold.

Task 11 work on the CeraMem filter was delayed and is expected to be started during the next reporting period. The first series of combustion testing of the low-NO_x firing system was completed and the data is being analyzed. Early review indicates that 0.1 lb of NO_x/million Btu is achievable with reasonable stoichiometry and carbon loss.

Plans for the next reporting period include: conducting the 200 acfm CeraMem filter test, continuing work on the POCTF preliminary design (with a Kalina cycle), conducting the second low-NO_x firing system test series, update all plans based on starting Phase III on October 1, 1996, and hold a Project Review Meeting for DOE/PETC.

TASK 1 - PROJECT PLANNING AND MANAGEMENT

All work in Task 1 and all Task 1 deliverables for the reporting period were completed on schedule. All quarterly reports and all monthly Status, Summary, Milestone Schedule Status, and Cost Management reports were submitted on schedule.

Annual updates of the following plans were prepared and will be submitted early in the next reporting period:

- Management Plan (including Work Plan)
- Milestone Schedule Plan
- Cost Plan
- QA/QC Plan

Preparations are being made for a Project Review Meeting at PETC early in the next reporting period.

Technology Transfer activities consisted of the following:

- Presented a LEBS paper at the 1995 International Joint Power General Conference entitled "Improving Pulverized Coal Plant Performance". A copy of the paper is included as Appendix B. The paper was delivered in a Combustion 2000 Session which was chaired by ABB and DOE.
- Received notification that a LEBS paper for the 21st International Technical Conference on Coal Utilization & Fuel Systems was accepted.
- Initiated organization of a Combustion 2000 Session at the 1996 International Joint Power Generation Conference (Houston, October 14-16, 1996).
- Agreed to submit an abstract of a paper for the Thirteenth Annual International Pittsburgh Coal Conference.

TASK 7 - COMPONENT DEVELOPMENT AND OPTIMIZATION

SNO_x™ Hot Process

Test equipment was delivered to Plant Miller and was subsequently moved from Plant Miller to a local storage facility. The test is on hold again, waiting identification of a host site.

Low-NO_x Firing System

The overall objective is to develop an advanced firing system which reduces the NO_x emission levels leaving the primary furnace to 0.10 lb/MMBtu or lower while maintaining carbon in ash at 5% or less. Included in this scope is an integrated effort combining Computational Modeling, fundamental scale evaluation of firing system concepts performed in the Fundamental Scale Burner Facility (FSBF), characterization of the pulverizer system performance utilizing the Pulverizer Development Facility (PDF), and pilot scale testing of the firing system in the Boiler Simulation Facility (BSF). The air toxics work, primarily an assessment of the potential for regulations, was completed during the reporting period.

Computational Modeling: Analysis of the various CFD simulations was performed. Included in these simulations was the TFS 2000™, along with variations of two (2) corner coal firing with air biasing between corners. Although there were differences in temperature, gas flow, species, and heat flux distributions within the lower furnace, these differences were insignificant at the furnace outlet plane (compared to four corner fuel injection). Based on the results of this modeling, two (2) corner coal firing with 4 corner air injection appears to be viable and was recommended for further evaluation in the Boiler Simulation Facility (BSF) combustion testing. Additionally, a "helical" arrangement was evaluated in which the fuel was introduced through two (2) opposed corners at a given elevation, alternating at subsequent elevations. Results from this simulation indicate improved performance compared to the two (2) corner fuel configurations and was also recommended for further combustion testing.

Bench Scale Corrosion: Firing conditions which occur in coal-fired boilers under low NO_x firing conditions have been shown to create local reducing environments at waterwall surfaces. Whenever CO concentrations exceed 6%v, total reduced sulfur (TRS) species such as H₂S, COS, and CS₂ have been detected at levels between 200 and 1000 ppmv.

Correlations from bench scale testing under this environment (isothermal conditions at 500°C) have been demonstrated between TRS content and wastage rate, thus providing a basis for predicting corrosion behavior. Statistical analysis of the data collected during this testing suggest the following dependence of SA-213 grade T-11 steel weight loss on H₂S gas content:

$$\text{Wgt loss (mg/cm}^2\text{)} = 7.74 \times 10^{-3} (\text{H}_2\text{S, ppmv})^{0.57} (\text{time, hours})^{0.86}$$

Extrapolation of this correlation to periods greater than 1500 hours or H₂S levels in excess of 5600 ppmv are subject to further verification.

Bench scale testing was performed in which separate samples of T-11 and chromized T-11 were exposed to a synthetic flue gas for a period of 500 hours. Based on this testing, chromized T-11 steel showed the greatest resistance to high temperature sulfidation due to sulfidation of the chromium carbide surface layer which appears to act as a diffusion barrier for further attack. The bare T-11 steel showed the maximum degradation rate under these simulated combustion gas conditions. Tp 310 stainless steel was found to experience some surface degradation, but was more protective than bare T-11. Under these same test conditions, Al-thermal spray coating on T-11 provided some resistance due to the formation of an interdiffusion Fe-Al layer at the metal surface. In addition, short term exposure (4 hours) of both T-11 and chromized T-11 was carried out during the BSF combustion tests at nominal 700°F waterwall temperatures. Conditions included the baseline (no over fire air) and the TFS 2000™ firing arrangements firing the Viking coal. Analysis of deposit samples was performed utilizing a state of the art scanning electron microscope (SEMPC), to better understand the morphology of microscopic components in the deposits. This analysis is currently being completed.

Coal Pulverization: Primary activities in this task included coal preparation for BSF combustion testing and subsequent repairs to the pulverizer and the fuel feed system. These repairs were necessitated by the pulverization of this fuel, as the Pulverized Development Facility (PDF) was designed as a test mill and does not have all the wear resistant components of a production unit. The raw coal used for these tests turned out to be more abrasive than standard coals previously used in PDF testing.

Shakedown tests of the classifier test facility were also performed and preliminary tests were performed to determine recirculating load. Results from this testing are currently being analyzed.

Air Toxics: A study was conducted of expected air toxics emissions and potential regulations. The results of this work are detailed in a report entitled "Low-Emission Boiler Systems and Potential Toxics Regulations Under the Clean Air Act Amendments of 1990". This report is included as Appendix C.

The EPA has tentatively found that air toxic emissions from the electric power generation industry do not constitute a health risk sufficient to require regulations specific to this industry. While the emissions of mercury compounds are expected to be studied further to clarify inconclusive results, it is believed that no utility air toxics emission regulations will be promulgated under the Act at this time. Because state and local regulations may be promulgated, or Federal regulations developed at some point in the future, it is important that LEBS be designed to address potential air toxics concerns.

TASK 8 - PRELIMINARY POC TEST FACILITY DESIGN

Site Selection

In October of 1994 ABB CE formally accepted the Richmond Power & Light (RP&L) offer of Whitewater Valley Unit No. 1 as the host site for the Proof-of-Concept Test Facility.

Kalina System Design

A feature of the Kalina technology is its ability to be reconfigured to meet the needs of the unit it is being applied to. A number of systems were evaluated for use in the POCTF at RP&L. In developing a system for RP&L, the following variables were evaluated: system pressure, temperature, number of reheaters and MW output. Pressures evaluated ranged from 1800 to 2400 psi at the turbine inlet. Combinations of temperatures from 1005 to 1050 °F for the superheater and reheater were looked at in combination with one or two reheaters. For economic reasons, outputs from 35 to 60 MW were evaluated. Constraints of existing infrastructure (coal and ash handling, structural steel, cooling tower, etc.) were included.

After reviewing and evaluating various configurations, a final configuration with a single reheat, 2400 psi, 1050/1050 °F, for approximately 48 MW net was selected.

Boiler: Prior to the RP&L project, ABB had developed boiler concepts that use ammonia/water as the working fluid for 240 and 400 MW designs. At the current time, a number of boiler designs are under evaluation. The primary concern in the selection of the design is that it provide safe and reliable operation. To accomplish this, discussions with the system designer (Exergy) have taken place to move and adjust heat pickup in various heat exchangers. This allowed ABB to evaluate operating the boiler at conditions ranging from liquid filled to vapor filled furnace tubes. Current design layouts of the heating surface are very similar to utility designs currently in operation. The firing system uses low NO_x burners. Heat release rates, excess air and gas velocities are conventional. The boiler consists of a furnace that is cooled with fusion welded wall tubes, a cross over tunnel with pendant heating surface and a back pass with horizontal heating surface. Both once thru and recirculation were evaluated for use in the furnace wall tubes.

In parallel with developing a boiler design, materials for the pressure parts are being evaluated both in the laboratory and at Exergy's Canoga Park test unit. NH₃/H₂O properties and heat transfer characteristics are also being investigated.

Turbine: In developing a turbine for the RP&L unit, a number of configurations were evaluated. With the support of the system designer (Exergy), multiple design iterations have taken place. In selecting the turbine, designs for a utility and "industrial" turbine were evaluated. Due to the small capacity and the available space for the turbine, an "industrial" turbine configuration has been selected. This configuration consists of a high pressure turbine, a set of reduction gears and a low pressure turbine. A conventional blade design is used in the turbines. With a Kalina cycle, a back pressure turbine can be utilized. Use of a back pressure turbine and recuperative heaters allows the use of a smaller condenser operating at positive pressure.

Currently under investigation is the evaluation of the location and number of extractions from the high pressure turbine. These extractions are used to provide energy to the recuperative section of the system.

In addition to the selection of the turbine design, material evaluation is underway for the proper selection of materials for an ammonia/water environment under the conditions that the turbine will experience.

Heat Exchangers: In designing the heat exchangers, Exergy is carrying out testing at their test facility located at Canoga Park. These tests are providing data on falling film characteristics to support the development of correlations to describe heat transfer that occurs in the heat exchangers. The new heat transfer correlations will provide data for heat exchanger design and fabrication.

In addition, Exergy is developing standards for the design of heat exchangers in the Kalina cycle. To maintain cost, Exergy is working with a heat exchanger fabricator to develop specialized designs to take advantage of the ammonia/water properties.

Impact of Firing System on Boiler Design

The performance of the convection pass was evaluated using test results (from an operating unit equipped with an earlier generation of the proposed firing system) for single and dual staged over fire air as well as for effects of fine grinding of the coal. Preliminary results indicate that the configuration of the firing system has a significant influence on the convection pass performance. The degree of grinding also affects the convection pass performance. The effects of both over fire air systems and grinding were found to impact the forward surface areas, such as the superheater platen, more significantly than the most rear sections, such as the economizer.

Three firing system configurations were evaluated: one comprised of close-coupled air (CCOFA), another including one level of separated air at a low level (CCOFA + LSOFA) and the last including an additional level of air to comprise three levels of air (CCOFA + LSOFA + USOFA). Data indicates that as the firing system is more

deeply staged, the absorption profile in the lower furnace is shifted upward, furnace outlet temperatures increase and the surfaces in the convection pass become less effective. As shown in Figure 1, the effect of the firing system diminishes with each progressive section up to the superheater rear section. Beyond this point, the effects appear to even out, causing a minimal change for larger surfaces.

Three levels of grinding were evaluated for the CCOFA windbox configuration, 75%-200Mesh, 80%-200Mesh and 85%-200Mesh. The results of the data analysis indicate that for the CCOFA firing system, the effects of the system are somewhat more pronounced throughout the backpass. This is illustrated as a percent change from standard grind in Figure 2.

The impact of the firing system on the waterwall performance will be evaluated following the second series of combustion tests in the BSF.

Plant Design

A site visit to the Whitewater Valley station was made with new key project team members to walk-down the facilities and to collect engineering data from the perspective of adding the Kalina cycle conversion to the overall project. Previous work at the site had concentrated on just installation of the low-NO_x firing system and the SNO_x system on unit 1. The complete unit 1 A/E drawing set was collected, shipped to Raytheon's offices, and copied in a format that produced legible, reproducible drawings (specialized electronic scanning techniques had to be used because of the age and condition of the drawings). Selected unit 2 drawings, as well as drawings from other station-wide projects, were also included in this set.

Integration and optimization of the Kalina cycle process design, involving design and performance of the boiler, turbine and heat exchangers, are the precursor activities to Raytheon's POCTF facility design work. These ABB activities have required much more effort than anticipated, such that the vendor design packages needed by Raytheon will require an additional two to three months to complete. As such, Raytheon has deferred any substantial work on the facility design until the required data is available.

Licensing

The licensing documents that have been completed to date will have to be revised to reflect the addition of the Kalina cycle to the project. To begin this revision process, an addendum to the DOE Environmental Questionnaire (NEPA) was prepared and reviewed in-house. Further distribution is on hold, pending potential revisions in the process design.

The primary licensing activities for the reporting period were structured around the objective of completing a package, consisting of the PSD permit application and the state construction permit application, for submission to Indiana Department of Environmental Management (IDEM).

Preparation of the PSD permit application involved two main activities that proceeded in parallel: completion of the background information on the project, and dispersion modeling of the sulfuric acid mist emissions. The former activity was readily completed, and the resultant document was distributed for project-team review. The modeling work proceeded as follows:

- A modeling protocol document was prepared and submitted to IDEM for approval.
- A memo describing the results of preliminary screening analysis of the acid mist emissions was prepared and distributed for project-team review.
- Comments on the modeling protocol were received from IDEM and incorporated in the procedure.
- The initial set of modeling calculations were performed and reviewed, and criteria for finalized calculations were defined.

Further work on the PSD permit application was then put on hold, pending potential revisions in the process design.

Application forms for the state construction permit were obtained from IDEM, and the application completed and readied for RP&L signature. Further distribution is on hold, pending potential revisions in the process design.

Figure 1

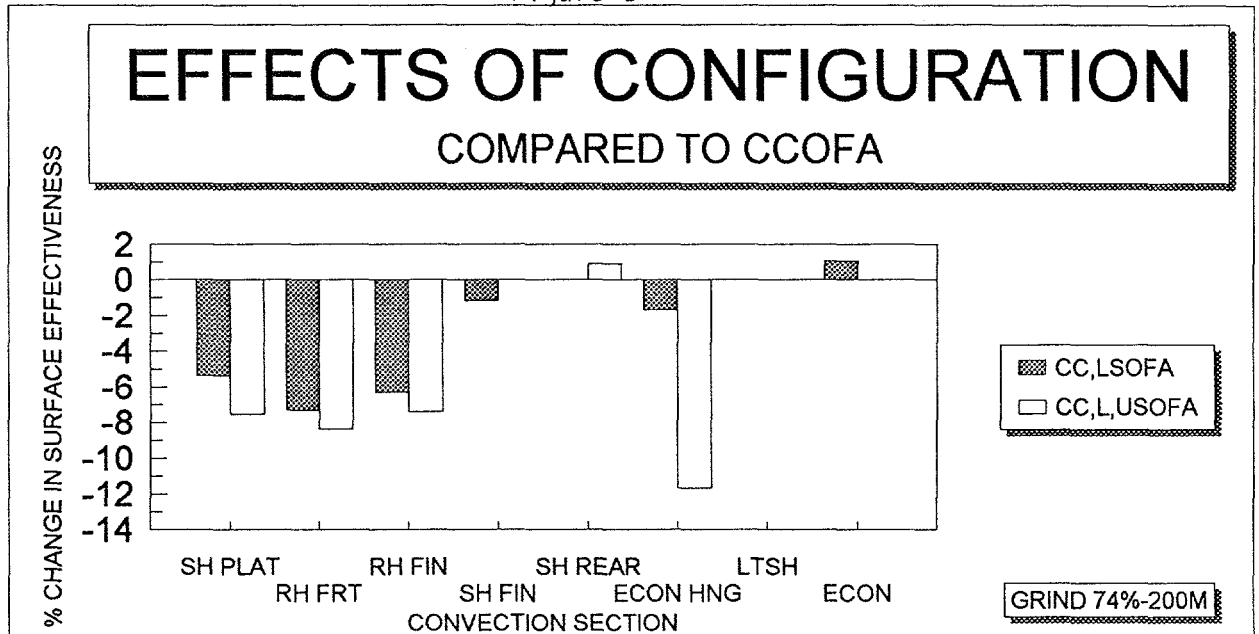
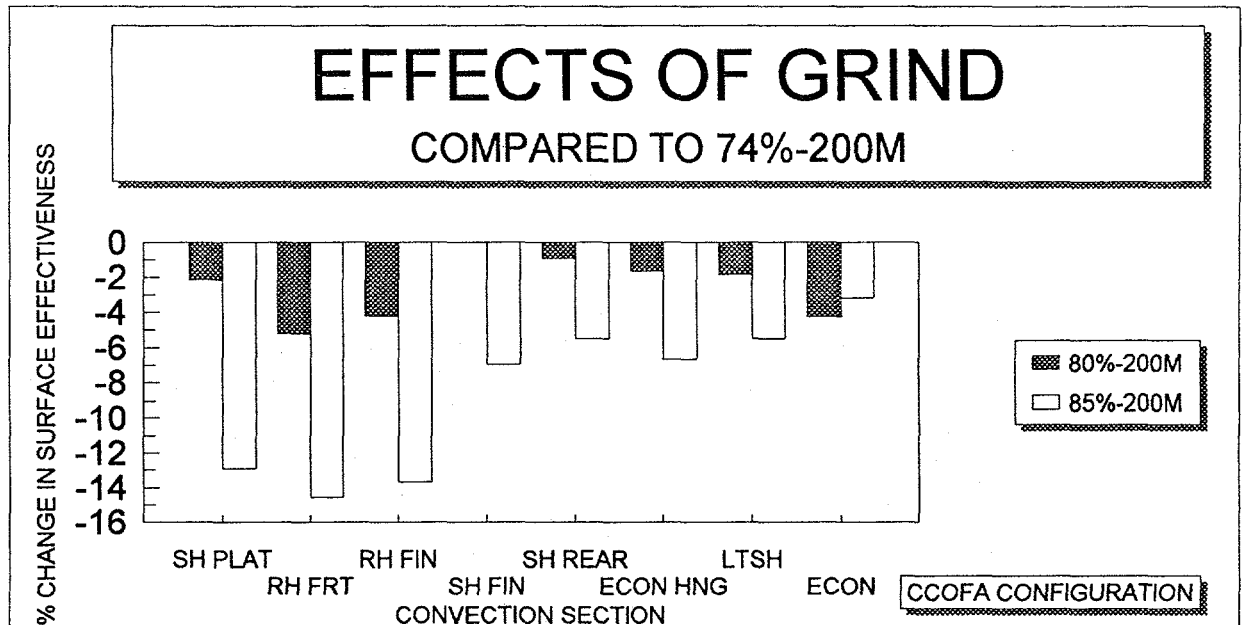


Figure 2



TASK 9 - SUBSYSTEM TEST DESIGN AND PLAN

SNO_x Hot Process

The Subtask 9.2 Test Plan was submitted to DOE for their approval/comments. The Plan will be finalized by adding details generated in Task 7.

Low-NO_x Firing System

Completed in a previous reporting period.

TASK 10 - SUBSYSTEM TEST UNIT CONSTRUCTION

SNO_x Hot Process

The test rig for the 5,000 acfm test has been shipped to the fabricator's shop, inspected, cleaned and is being modified to operate under process conditions.

Low-NO_x Firing System

The Boiler Simulation Facility (BSF) was inspected and prepared for the second series of tests. No major modifications were required.

TASK 11 - SUBSYSTEM TEST OPERATION AND EVALUATION

SNO_x Hot Process

See Task 10 above.

Low-NO_x Firing System

The first of two series of pilot scale combustion tests was performed in the Boiler Simulation Facility (BSF.) The objective of these tests was to characterize the performance of the present LEBS Low NO_x firing system (the TFS 2000™) for input into the firing system design for the Proof-of-Concept test facility (POCTF.) Additionally, advanced firing systems were evaluated for potential reductions in outlet NO_x emissions and carbon loss, along with potential cost reductions. Testing was performed using a 90% thru 200 mesh grind of the Viking coal from Montgomery, Indiana. This coal is a high volatile, high sulfur coal which is the as-fired coal at Richmond Power & Light, the proposed site of the POCTF.

During this testing, a total of 57 combustion tests were performed, including characterizations of the TFS 2000™ and other advanced firing systems. Recorded data typically included furnace inlet mass flows (air and fuel), furnace outlet emissions (O₂, CO, CO₂, SO₂, NO, AND NO_x), and vertical heat flux distribution. Additionally, iso-kinetic solid samples were obtained at the outlet duct for selected test conditions.

The data is being analyzed. Highlights of the results include:

- The baseline firing system with only close coupled over fire air (CCOFA) had NO_x emissions of 370 ppm, carbon in ash (CIA) <5%, and a peak vertical furnace outlet plane (VFOP) heat flux of 13% greater than average.
- The TFS 2000™ firing system had NO_x emissions of approximately 100 ppm (0.13 lb/million Btu), CIA <5%, and a VFOP heat flux of 12% greater than average.
- Biasing of the fuel and air between the four (4) main windboxes (horizontal staging) under deeply staged conditions had a slightly negative effect on NO_x with no appreciable change in unburned carbon.
- The "helical" coal injection firing system, under deeply staged conditions, demonstrated a repeatable 10% reduction in NO_x over standard four (4) corner coal injection with no appreciable change in unburned carbon. This firing arrangement consists of two (2) opposed coal injection points at a given windbox elevation, alternating corners at subsequent elevations. A test period low of 82 ppm (0.11 lb/million Btu) NO_x was demonstrated with this firing system on the Viking coal.

- An advanced single separated over fire air (SOFA) firing system had NO_x emissions of approximately 91 ppm, CIA <5%, and a VFOP heat flux of 13% greater than average.
- An advanced no SOFA, high CCOFA firing system had NO_x emissions of approximately 225 ppm, CIA <5%, and a VFOP heat flux of 8% greater than average.

Finally, planning activities for the second week of BSF combustion testing was done. This work will focus on providing design information for the firing system to be utilized in the POCTF. In addition, further investigation of horizontal staging at higher main burner stoichiometries and continued investigation of the helical firing system will be performed, focusing on repeatability and isolating important design variables.

PLANS FOR NEXT QUARTER

Task 1

- Issue updated Management Plan (with Work Plan), Milestone Schedule Plan, Cost plan and QA/QC Plan.
- Hold Project Review Meeting at PETC.

Task 7

- Conduct 200 acfm CeraNO_x test.

Task 8

- Continue work on the POCTF preliminary design.
- Evaluate NID as a backup to Hot SNO_x.

Task 9

- Complete the test plan for the 5,000 acfm CeraNO_x test.

Task 10

- Complete reconfiguration of the test rig for the 5,000 acfm CeraNO_x test.
- Modify the Boiler Simulation Facility (BSF) for the second low-NO_x firing system test series.

Task 11

- Initiate the 5,000 acfm CeraNO_x test.
- Conduct the second BSF test series.

APPENDIX A - 2 pages

U.S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE ☐ PLAN ☒ STATUS REPORT

Page 1 of 2
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4. PARTICIPANT NAME AND ADDRESS		5. START DATE												b. Actual													
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P.O. Box 500		6. COMPLETION DATE																									
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1.0	PHASE II																									50	50
7.0	Prj Mgt																									69	66
8.0	Comp Dev																										
8.1	POCTF																										
8.2	Site Sel																									100	100
9.0	Pre Dsn																									27	27
9.1	Subsyst																										
9.2	Design																									100	100
10.0	Plan																									100	95
11.0	Constr																									84	80
11.1	Subsyst																										
11.2	Oper																									21	14
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11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE
John W. Regan JAN. 5, 1996

APPENDIX B - 9 pages

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separate cycling at*

**LOW-EMISSION BOILER SYSTEMS AND POTENTIAL
TOXICS REGULATIONS UNDER THE CLEAN AIR ACT
AMENDMENTS OF 1990**

FOR:

**U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER**

CONTRACT DE-ACC22-92PC92159

**ENGINEERING DEVELOPMENT OF ADVANCED COAL-FIRED
LOW-EMISSION BOILER SYSTEMS**

SUBMITTED BY:

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Executive Summary

The Clean Air Act Amendments of 1990 greatly expanded and enhanced air quality protection. Existing clean air legislation was supplemented with new titles for acid rain, protection of the ozone layer and facility operating permits. Existing titles were also enhanced to further control sources of air toxics and those pollutants that contribute to an area's failure to meet and maintain national ambient air quality standards.

Detailed and rigorous regulations controlling air toxic emissions are contained in Title III of the Act. Air toxics are trace substances that are typically carcinogens, mutagens and reproductive toxins. The U.S. Environmental Protection Agency (EPA) estimates that air toxics result in 1000 to 3000 cancer deaths a year, as well as, contributing to numerous other health effects.

Air toxics regulations went into immediate effect for most industries, including the chemical process industry, the largest single source of air toxic emissions. The electric power generation industry, however, received special consideration under Title III. Because of major uncertainty over the magnitude, species and health effects of air toxic emissions, EPA was mandated by Congress to conduct a detailed study of the subject emissions and health risks. If the EPA Administrator finds, based on that study, that specific air toxics regulation of electric utility steam generating units is "appropriate and necessary" he/she must commence such regulation.

Accordingly, the EPA coordinated a field measurement program at 60 operating fossil-fueled power plants in partnership with the Electric Power Research Institute (EPRI) and the U.S. Department of Energy. The results of these measurements were then modeled to assess the health impact of the 600 U.S. fossil power plants with their 1800 boilers.

The EPA has tentatively found that air toxic emissions from the electric power generation industry do not constitute a health risk sufficient to require regulations specific to this industry. While the emissions of mercury compounds are expected to be studied further to clarify inconclusive results, it is believed that no utility air toxics emission regulations will be promulgated under the Act at this time. Because state and local regulations may be promulgated, or Federal regulations developed at some point in the future, it is important that LEBS be designed to address potential air toxics concerns.

1.0 Overview

This review was carried out to examine the development of the Clean Air Act Amendments (CAAA) of 1990 and the potential applicability of its Title III (Air Toxics) to the electric power generation industry. As will be discussed in detail, the electric power generation received special consideration under the CAAA of 1990. That is, the EPA was mandated by Congress to conduct a detailed study of the subject emissions and health risks. If the EPA Administrator finds, based on that study, that specific air toxics regulation of electric utility steam generating units is "appropriate and necessary" he/she must commence such regulation.

This paper demonstrates the evolution of the Federal environmental regulatory process from a "command and control" approach to a science-based methodology by examining the process currently underway to determine whether or not it is necessary to promulgate Air Toxics emissions regulations specific to the electric power generation industry under Title III of the Clean Air Act Amendments of 1990.

Therefore, in conjunction with the development of Low-Emissions Boiler Systems (LEBS), it is important to stay abreast of air toxics regulatory activities and be prepared to act if need be.

2.0 Introduction

Protection and improvement of air quality is a cornerstone of the U.S. environmental policy, legislation and regulation. The federal statutes under which this is primarily accomplished are the Clean Air Act and its Amendments. The initial statute to bear the title "Clean Air Act" was enacted in 1963. The 1967 Air Quality Act provided federal guidance to the states in controlling sources of air pollution. However, it was the Clean Air Act amendments of 1970 that established the present statutory scheme and massively overhauled the original legislation. In 1977, the Act was again extensively modified and included initial, but limited, regulation of air toxics.

The Clean Air Act Amendments (CAAA) of 1990 greatly expanded the scope of the CAAA of 1970 and 1977. The 1990 amendments added new titles for acid rain, protection of the ozone layer and permits. Existing titles were enhanced to further control sources of air toxics and those pollutants that contribute to an area's failure to meet and maintain the national ambient air quality standards.

This report describes the Clean Air Act Amendments of 1990 in general, the Air Toxics (Title III) provisions in detail, and concludes with a discussion of the application of Title III to three affected industrial segments.

3.0 Legislative Development

The legislative process to develop the text of the 1990 Clean Air Act amendments was long and difficult. These were the first changes to the Clean Air Act in thirteen years. Laborious and extensive negotiations were required during the course of 1990 by a Congressional Conference Committee to resolve numerous issues in order to reconcile the House (H.R. 3030) and Senate (S. 1630) Bills. Participants spoke of thousands of hours of work, thousands of compromises, large and small, and sessions continuing until three or four o'clock in the morning(1). Wyoming's Senator Alan Simpson summed up the negotiations: "It was rich, profane, embittered. I learned that [California Representative] Henry Waxman is tougher than a boiled owl." (2)

The legislation was signed into law on November 15, 1990 by President George Bush. Michigan representative John Dingell described it as "the most complex and comprehensive and far-reaching environmental law any Congress has ever considered." (3)

Lawmakers from both Democratic and Republican parties gave considerable credit to President Bush. Representative Waxman, a California Democrat, explained why it had taken 13 years to amend the Act and how President Bush made the difference:

"The Regan administration started the decade by pledging to eviscerate the Clean Air Act. They proposed doubling the amount of pollution from cars, weakening the air quality protections for our national parks, and diluting the act's standards. They urged us to fight ozone depletion with sunglasses, sunscreen and sunhats. They told us that acid rain always needed another study, and that we had no toxic air pollution problem. That decade of neglect is over.... President Bush deserves great credit for breaking this stalemate." (4)

Although the 1990 amendments passed Congress by a considerable margin, opponents bitterly criticized their potential cost to industry, especially because as many as 150,000 previously unregulated businesses would have to obtain air emission permits under Title V.

Overall, the 1990 amendments are enormously comprehensive and complex. The prior Act consisted of approximately 70,000 words and was considered to be remarkably complicated. The 1990 amendments added 145,000 new words, tripling the total length of the Act and geometrically increasing its complexity. Representative Dingell referred to it as "five or six separate bills rolled into one." (5)

As had become common with federal legislation of the period, a heavy burden of the implementation was put upon the states. The 1990 Act repeatedly (on the order of 250 times) instructs state air pollution control agencies to submit, by enumerated deadlines, highly detailed revisions to their existing implementation plans.

In order to facilitate implementation of the Act, and to improve its cost effectiveness, EPA 'reinvented' its approach to issuing regulations. The agency adopted a new policy of communicating and consulting with the regulated community, discontinuing its traditional adversarial stance. The Federal Advisory Committee Act and the Negotiated Rulemaking Act of 1990 have enabled EPA to form negotiating committees that represent industry, regulators, environmentalists and academia. Using this approach EPA is working to avoid being sued after the regulation is issued, a common occurrence under earlier versions of the Clean Air Act. (6)

Another shift lawmakers and regulators hope to obtain under the CAAA of 1990 includes harnessing the marketplace to control pollution in the most cost-effective manner. The most best known example of this principle is the SO₂ credits trading taking place under Title IV. This system turns one ton of sulfur dioxide emissions into a marketable commodity that may be sold, traded or retained by anyone. Title III (Air Toxics) reflects this market-based approach by rewarding early and voluntary reduction of specific amounts of emissions with an extra six years to comply with specific new standards.

3.1 Air Toxics Provisions in the 1990 Clean Air Act

Title III establishes an extensive expansion of materials considered to be hazardous air pollutants. Under the CAAA of 1990, 189 chemicals (elements and compounds) are listed as air toxics. Air toxic pollutants are typically carcinogens, mutagens, and reproductive toxins. (EPA estimates that air toxics may result in 1000 to 3000 cancer deaths each year).

The 1990 legislation does not affect the applicability of the National Emission Standards for Hazardous Air Pollutants (NESHAP) that were issued under the 1970 and 1977 versions of the Act. NESHAPS exist for asbestos, benzene, beryllium, inorganic arsenic, mercury and radionuclides. EPA was, however, given authority under the 1990 Act to change or expand the

regulation of sources of Hazardous Air Pollutants (HAPs) already covered under NESHAP. An example of the use of this expanded power is given later in this report.

Under the 1990 Clean Air Act Amendments, EPA must identify source categories or subcategories that emit any of the 189 listed air toxics. Following identification of the sources, EPA must issue technology-based standards, on varying schedules^{*}, within ten years. Following application of the control technologies, EPA must determine if residual risk remains. If so, health-based standards must be issued.

3.2 Technology-Based Emission Standards

Under the 1990 Clean Air Act Amendments, EPA must base the first round of emissions limits on technological controls. Distinctions may be made by EPA among classes, types, and sizes of sources when setting emissions standards. Standards must be reviewed for possible revision at least once every eight years.

Emissions standards for new and existing sources must achieve the maximum degree of emissions reduction that EPA finds achievable. Cost, environmental and non-health effects, and energy requirements may be taken into account. The standards may require such things as process changes, or material substitutions, enclosures, and measures to collect, capture, or treat process, storage, stack, or fugitive dust emissions.

Standards for new sources must be based on maximum achievable control technology (MACT), defined as not less stringent than the emission control achieved in practice by the best controlled similar source.

*** Footnote on schedules:** Because of the massive number of specific tasks heaped upon the EPA Administrator by the 1990 Clean Air Act Amendments, most required dates have not been met. The CAAA contain the phrase "the Administrator shall" 615 times, many of these required tasks specify completion within one year, eighteen month, or two years. This has resulted in continuous negotiations between EPA, Congress and environmental groups to prioritize the work and set revised schedules. This report attempts to differentiate between originally mandated dates and actual completion dates in its text.

Standards for existing sources may be more or less stringent than MACT standards, but may not be less stringent than the following levels:

- For a listed category or subcategory containing 30 or more sources, a standard would have to be based on the average emissions limit achieved by the best performing 12 percent of the existing sources in that category.
- For categories with less than 30 sources, a standard would have to be based on the average emissions limit achieved by the best performing five sources in that category.
- For categories with 30 or more sources, a source that achieves the lowest achievable emission rate 18 months prior to the standard's proposed date, or 30 months prior to its final issuance (whichever is later) would be exempt from the standard.
- Standards for area sources may be less stringent than for major sources, but must be based on generally achievable control technologies or best management practices. Sources that could be listed as area sources include: gas stations, woodstoves, hospitals and clinics. Area sources representing 90 percent of the area source emissions of the 30 toxics that present the greatest threat to public health in the largest number of urban areas are subject to regulation no later than November 15, 2000. (6)

3.3 Health-Based Standards

According to the original schedule within the Clean Air Act Amendments of 1990, EPA must report to Congress, by November 15, 1996, on residual risk from air toxics emissions. This must include consultation with the surgeon general and obtaining public comment. The report must also include discussion of the methods used to calculate the risk remaining or likely to remain from sources after compliance with technology-based emissions standards, the significance of the remaining risks and the available methods and cost for reducing the remaining risk, and the actual health effects on persons near the source. A health-based standard must be issued if a technology-based standard does not reduce the lifetime excess cancer risks to less than 1-in-1 million to the maximally exposed individual.

Health-based standards must provide an ample margin of safety to protect public health, unless a more stringent standard is necessary to prevent an adverse environmental effect. EPA must consider costs, energy, safety, and other relevant factors in the formulation of this more stringent standard.

4.0 Selected Applications of Title III to Industry

In order to establish a frame of reference for the treatment and issues specific to the electric power generation industry, two other industrial segments are briefly examined.

4.1 The Chemical Process Industry

The chemical process industry (CPI) is a key target of Title III. The CPI contains many of the major sources of HAPs. It emits the lion's share of the nearly 3 billion pounds of annual air toxic emissions in the United States (7).

A source is defined as a major source if it has the potential to emit 10 tons per year or more of a single HAP, or 25 tons per year of any combination of HAPs.

As of November 1994, EPA had issued three rules in final form establishing MACT standards for categories of sources. The most comprehensive rule is the Hazardous Organic NESHAP (HON) for the synthetic organic chemical manufacturing industry (59 FR 19402, April 22, 1994).

This HON rule is very lengthy and complex. It regulates emissions of listed organic chemicals from both new and existing chemical manufacturing sources and from equipment leaks at certain sources with polymer and resin production processes. EPA also issued MACT standards for perchloroethylene dry cleaners (58 FR 49354, Sept. 22, 1993), and coke ovens (58 FR 57898, Oct. 27, 1993).

The deadline for promulgating MACT standards for the next group of sources categories was November 15, 1994. This deadline passed without EPA action. Thirty-eight MACT standards were required to be published by that date including those for the petroleum refining industry, halogenated solvent cleaners (degreasers), gasoline distribution facilities (bulk and marine terminals), aerospace industry, chromium electroplating, magnetic tapes (surface coating) and secondary smelters. Most of these overdue Title III MACT standards were expected to be issued in 1995.

The imposition of Title III (and relatedly Title V) requirements, as well as, numerous increasingly stringent environmental regulations (e.g., expansion of the Clean Water Act Amendments and Great Lakes Initiatives) come at a critical time for the American chemical manufacturing industry. These companies are attempting to generate increased profits and compete in the global marketplace in the face of decreased internal resources and expanding foreign competition. While management is focusing on production and profitability, environmental staffs are being decreased, while the remaining personnel are busier than ever.

The counterpoint to this outcry from the chemical industry is a reminder from Mary Nichols, EPA assistant administrator for air and radiation, remembering the "twenty years of emissions and exposures into thousands of communities.....the companies released billions of tons of toxic chemicals into communities surrounding their own facilities." (7)

While the controls mandated for the chemical industry under Title III regulations are expensive, they are also, based on historical industry conduct, quite necessary.

4.2 Small Businesses

The CAAA of 1990 addresses many entities which have never previously been thought of as polluters and never been involved in environmental matters. "Hundreds of thousands of new actors will soon be dragged into the Clean Air Act's regulatory arena, including painters, plumbers, electricians, gasoline service stations, auto repair shops, dry cleaners, schools, local transportation systems (taxicabs and buses), municipal police departments, drinking water treatment plants, janitorial services, trucking companies, pharmacies, hospitals, publishers and printers, food processors, farmers, builders, spinners, weavers, restaurants and retail stores." (1)

While the air quality impacts of these businesses are individually small to negligible, they collectively constitute a significant source of HAPs emissions. Consideration must be given, however, to the cost effectiveness and fairness of regulations specific to each industry. Small businesses are an increasingly important component to the American economy. Many of these businesses operate on small profit margins. Imposition of non cost-effective air toxics requirements could produce a disruptive effect to the economy with only marginal benefit to air quality.

4.3 The Electric Power Generation Industry

During the formulation of the CAAA of 1990, the significant uncertainty over the species and magnitude of HAPs emissions from electric power generation resulted in deferral of industry-specific regulatory mandates. In order to clarify the situation and determine the necessity for controls, the EPA was directed to perform a study of the public health hazards reasonably anticipated to occur as a result of the hazardous air pollutant emissions by electric steam generating units, "after imposition of the requirements of the Act." (8)

The EPA was to report the results of this study to Congress within three years of enactment. EPA failed to meet the original deadline, November 15, 1993. This report was to be delivered to Congress on November 15, 1995. This has been further delayed to 1996. A draft version of the report was issued in June 1995 and is in circulation for comments. This report is discussed in detail in section 4.3.3.

If the EPA Administrator (Carol Browner) finds, based on this study, that specific HAPs regulation of electric utility steam generating units is "appropriate and necessary" (9) she must commence such regulation.

The industry counterpoint to the potential HAPs regulation is being led by the Electric Power Research Institute (EPRI). As discussed in sections 4.3.1 and 4.3.2, EPRI, and also the U. S. Department of Energy, have conducted extensive HAPs sampling of flue gases from approximately 60 utility boilers using highly sensitive sampling techniques. The results were used by EPA as input to the risk study mandated by the Act.

4.3.1 DOE Field Measurement Program

A key element in the process was the measurement of air toxics emissions from actual power plants. In January 1993, the DOE initiated a program to determine the concentrations of toxic emissions emanating from coal-fired electric utility boilers. Additional goals of the program were to: (1) determine the ability of conventional air pollution control equipment to remove air toxic species from flue gas; (2) determine the concentrations of toxic substances associated with particulate matter as a function of particle size; (3) quantify toxic materials on the surfaces of

particulate matter; (4) determine material balances for selected trace elements in all major input and output streams; and (5) measure the concentrations of condensable toxic species in flue gas.

The DOE Air Toxics Assessment Program was structured in two phases that would provide emissions data from a total of sixteen power plants (eight plants in each phase). Results from the first phase, conducted in 1993, have been summarized by Schmidt and Brown of the DOE and is extensively utilized in this section (9). The second set of tests in phase II were to have been conducted in 1995. These tests have been deferred to 1996 and will be refocused in order to more accurately quantify and speciate mercury emissions (10).

Phase I Power Plants. The eight power plants tested in 1993 are listed in Table 4-1. Also included in Table 4-1 are the air pollution control devices, boiler size and type of coal burned. The plants chosen for Phase I were picked to be representative of the general population of electric utility boilers in the U.S. They have several types of pollution control technologies, and include plants that burn bituminous, sub-bituminous and lignite coals. The selection of the plants was coordinated with EPRI and with the Utility Air Regulatory Group and the EPA to acquire adequate emissions data from all the major coal-fired boiler types for the Title III study.

In order to assess the air toxics control capability of advanced pollution control technologies currently under development and demonstration, three of the utilities chosen to participate in phase I are also sponsoring demonstration projects under the Innovative Clean Coal Technology Program (ICCT) of DOE. They are: (1) the Bailly Station of Northern Indiana Public Service Company, which is hosting an advanced wet limestone scrubber by Pure Air; (2) Georgia Power's Yates Station with the Chioda CT-121 Jet Bubbling Reactor wet limestone scrubber; and (3) the Niles Station of Ohio Edison, where an integrated NO_x and SO₂ removal system, called SNOX, is being tested. The inclusion of these advanced power plants assisted EPA in complying with the Title III requirement that the risk assessment reflect the boiler population after the Clean Air Act Amendments titles are promulgated, i.e., in the year 2000.

Emissions Measurements. The field sampling activities were designed to provide comprehensive sampling of solid, liquid and gaseous streams for detailed, multimedia tracking of the air toxic elements in transit through the power plant. Because of the sensitivity and of the test methods, a rigorous test plan was followed. Three inorganic compound and three organic compound days, plus one day for field blank determinations, were scheduled for flue gas sampling

at each site. Each contractor provided for on-site QA/QC oversight to ensure the integrity of the samples.

Extensive power plant operating data were collected during sampling to document the process stream flows and the calculation of component material balances. The power plants were operated at as near steady-state conditions as possible to provide the most stable and representative emissions.

About 1000 analytical determinations were necessary at each power plant for air toxics emissions. An elaborate regime of sample analysis, calibrations, blank and QA/QC samples were used to ensure the accuracy and integrity of the field measurements. In some cases, newly developed sampling techniques were tested and evaluated against existing standard methods.

Results. When coal is burned, trace elements associated with the mineral matter (ash) are released in both solid and vapor forms. Those trace elements that are not vaporized during combustion become part of the bottom ash stream or exit the combustor entrained in the flue gas as fly ash matter. The trace elements that are vaporized during combustion will exit the combustor as gases, and subsequently condense as submicron particles, or on the surface of particulate in the flue gas stream. Some details of the mineral matter transformation process are shown in Figure 4-1. Fine particulate matter (fly ash) becomes a carrier of a disproportionate percentage of inorganic air toxic compounds.

Inhalation is the main pathway by which air toxics released by coal-fired power plants can enter the human body and affect human health. As shown in Figure 4-2, electrostatic precipitators (ESPs), are the dominant particulate control technology used by the power industry. ESPs (See, example, Figure 4-3) are very effective at removing particles greater than 10.0 microns in diameter. However, the efficiency drops off considerably in the respirable 0.1 to 5 micron range (Figure 4-4). These are the most likely to impact human health. For this reason, air toxic compound distribution was documented as a function of fly ash particle size. Trace elements exhibiting the most enrichment on fine particles were: cadmium, molybdenum, arsenic, lead, chromium and antimony(9).

Mercury. There is considerable interest in determining the amount of mercury released from the combustion of coal to generate electricity. The health effects of mercury are not fully established

and are highly controversial. A detailed discussion follows in section 4.3.3. Title III of the CAAA of 1990 requires EPA to conduct three separate investigations dealing with determining the sources and amounts of mercury emissions, as well as, assessing the environmental and human health impacts of mercury emissions. The first deals with mercury emissions from electric utility steam generating units, municipal waste incinerators, and other sources. The second with the atmospheric deposition of mercury (including other HAPs) in the Great Lakes, Chesapeake Bay, Lake Champlain, and Coastal waters. The third report to Congress (14) is the study of the hazards to public health posed by emissions of mercury (including other HAPs) from electric steam generating units.

Two independent methods were used to measure mercury at each power plant. Agreement between the two methods was good.

All of the stack emission data were converted to emission factors that relate the concentrations of HAPs released to the atmosphere to the amount of coal burned in the boiler. Emission factors for the eleven trace elements in the Title III list of HAPs and selected organic compounds are given in Table 4-2. The ranges represent a composite of the emission data from each site.

The major finding of the field sampling by DOE was that HAPs are present in extremely low levels in boiler flue gas (see Table 4-2), typically from a small fraction of a pound to a few pounds per trillion (1,000,000,000,000) Btu. (A trillion Btu is approximately 45,000 tons of coal, which would fill approximately 450 railroad cars and generate about 100 million kilowatts of electricity). This quantification could now be used with other recently obtained measurements to quantitatively assess the health risk associated with air toxic emissions from electric utility industry.

The other important finding of the DOE program, also shown in Table 4-2, was that the newly obtained concentration data, obtained with the most modern techniques, was considerably lower than that given in the earlier literature (9). This significantly decreased the estimated contribution of utility steam generators to total air toxics emissions. These findings have contributed to the accuracy of the health risk study.

The environmentalists response to the low levels on a per ton basis is that over 800 million tons per year of coal are combusted in the United States to produce steam for electric power

generation (11); hence, total electric generation emissions are significant, and, therefore, require regulation and control.

4.3.2 EPRI Risk Analysis Program

As part of industry's proactive stance on the air toxics regulatory issue, EPRI conducted their own risk analysis using the same field data pool as EPA. The EPRI study was an integrated assessment of the emissions, transport, fate, and health effects of trace substances emitted from over 1700 operating units plants at 600 power plants. The estimates were based on 51 measurement exercises at 43 sites to characterize the contents in fuels, control efficiency, and stack emissions of 16 substances; the data were, ultimately, extrapolated to all 600 sites nationwide. Exposures to individuals and populations were calculated for the air pathway (via inhalation) nationally, and for multimedia substances and radionuclides at selected case study plants. See Figure 4-5.

The Electric Power Research Institute, the research and development co-op of member U.S. electric power producing utilities had learned a hard lesson in the 1980's from the Acid Rain regulatory development process. EPRI had taken a weak stance during the acid rain debate. EPRI and the utilities had essentially denied that acid rain existed or that their burning of high sulfur coal was the major source of acid rain precursors. By the time the EPRI and the industry recognized the untenability of their position, the momentum to strongly control acid rain was too high to stop. This was not be the case for air toxics.

EPRI had undertaken a series of studies of fossil-fueled utility stack emissions of trace substances since the early 1980's, with work accelerating in 1990 prior to passage of the amendments to the CAA. The EPRI work was organized around two integrating projects: PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) and CORE (Comprehensive Risk Evaluation).

PISCES carried out 51 trace substance measurement programs at 43 operating sites, while CORE provided information on atmospheric and other environmental pathways, intermedia transfer, human exposure, and health risks of these emissions. The results were reported in 1994. This report by EPRI, entitled "Electric Utility Trace Substances Synthesis Report", provides

detailed information on site measurements carried out, on health effects studies, of trace substances, and on human exposure and potential health risks from these substances. The results of the measurement programs were combined with other data to evaluate community health risks from each of 1750 generating units at each of 600 power plants, as configured in the datum year of 2010. This future perspective is consistent with the requirements of the CAAA of 1990 that looks at utility air toxic emissions after future tightening of controls on SO₂ and other regulated emissions. The results of these analyses are discussed below.

Emissions Measurements. In order to improve the database on emissions from operating utility units, a measurement program organized under the EPRI PISCES program carried out 43 field sampling exercises at fossil-fuel fired utility power plants in the U.S. Figure 4-6 displays the mix of power plants sampled (29 coal, 13 oil and 9 gas sites). This field sampling included trace substance measurements in fuels received, plant process streams, and stack emissions locations. Additional data was added from the previously discussed DOE program at 8 coal-fired sites. The substances measured in the EPRI program were those known or suspected to be contained in boiler flue gas and were on the CAAA list of 189 HAPs. These included:

arsenic	chlorine	lead	PAHs
benzene	chromium	manganese	radionuclides
beryllium	dioxins/furans	mercury	selenium
cadmium	formaldehyde	nickel	toluene

The sampling efforts were made even more challenging because of the difficult settings (high temperature and flow conditions, dust loadings, noise, etc.).

Industrywide Emissions Assessment. In order to project these limited data to all 1750 operating units at 600 modeled power plants, several methods were required, depending on how robust the measurement data sets were for individual substances, fuel types, and power plant configurations. A complex rationale was applied to the metals data to assign the most accurate values to the projected emissions.

These factors were applied to each unit and each power plant was projected to be operating in the year 2010. The operating scenario was developed independently by EPRI and EPA and was

supplemented by survey data on planned particulate control changes by utility operators before the year 2000.

Exposure Calculations. The projected emissions, categorized by stack and by substance, were used as input to the EPA current atmospheric dispersion model, used to calculate downwind ground-level concentrations. These concentrations, particularly the maximum ground-level concentrations, were used in combination with exposure scenarios to represent long-term inhalation exposure concentrations, or exposure dosages. Two exposure scenarios were used. In one, the "maximally-exposed individual (MEI)," all assumptions of exposure to outdoor air concentrations are at their most conservative. The second measure, "reasonably exposed individual (REI)," assumed a more "realistic" pattern of human activity throughout a lifetime of exposure, incorporating survey data on indoor and outdoor physical activity and breathing rate, and on natural patterns for residency and commuting to and from job locations. Table 4-3 summarizes the key assumptions in these two measures of individual exposure. In addition, population-weighted exposures were calculated, to account for individuals exposed to levels less than the maximum experienced from each power plant, and to incorporate exposures to plumes from more than one power plant within 30 miles of a receptor location.

Health Effects. The exposure dose information for each substance was then combined with health effects information on the respective substances to calculate health response and consequent risks. These health effects data were taken from the EPA IRIS (Integrated Risk Information System) database, with the exception of arsenic which was affected by newer data.

For a carcinogenic effect, the risk measure is the probability of a cancer occurrence over a 70 year lifetime. For toxic effects, the ratio of the exposure concentration or dose to reference concentration is taken as the measure of risk. Levels below 1 are taken to represent insignificant risk of toxic reaction via inhalation. The inhalation hazard index is then, the summary across all substances to which the individual has been exposed.

Since mercury (and other substances, such as arsenic) have pathways to human exposure through environmental media other than air, a more complex set of exposure models was developed to provide insight into these alternative pathways. This model, called TRUE (for Total Risk of Utility Emissions), was applied to four case study power plants for which measurement and environmental data were available.

Results and Conclusions of EPRI Study. Figure 4-7 displays the distribution for all power plants of the inhalation carcinogenic risks, for the year 2010 base case, for both MEI and REI exposure scenarios. Even for the "worst case" MEI assumption, only 3 power plants (out of approximately 600) display inhalation carcinogenic risks above one in one million.

Figure 4-8 shows the range of inhalation carcinogenic risks by fuel type, and Figure 4-9 displays similar information for toxic (non carcinogenic) risks.

In a recent paper by Leonard Levin, the EPRI project manager points out that " a number of base case assumptions contain inherent conservatisms that imply that the results are themselves overestimates of what putative observations would show. For example, the unit risk factor values used for inhalation carcinogenic risk calculations are based on the 95th percentile outcome of a dose-response model valuation of animal and/or epidemiological oncology data. Nevertheless, even when extreme-value estimates of exposure are used, only 3 of 600 power plant exhibit inhalation carcinogenic risk. When more reasonable estimates of exposure, similar to those recommended by EPA and the National Academy of Sciences, are employed, these values drop by between 50 and 80 percent (11).

In summary, the results of the EPRI study "indicate risks of cancer by inhalation are below one in a million for all but 3 (of 600 power plant) locations even under worst-case assumptions, and well below one in one million for all locations under 'realistic' conditions. Risks for non-cancer toxic effects are all below federal guideline levels, even when exposure to multiple power plants emissions are considered. Multimedia risks, including those for mercury, are below federal advisory or threshold levels at all 4 case study sites." (12)

4.3.3 EPA's Report to Congress

As an amendment to section 112 of the CAAA of 1990, Congress mandated the Environmental Protection Agency to "perform a study of the hazards to public health reasonably anticipated to occur as a result of emissions by electric utility steam generating units of...[hazardous air pollutants]...after imposition of the requirements of this Act." The list of HAPs is presented in section 112(b) of the Act. Section 112 also requires:

- That the results of this study be presented in a report to Congress by November 1993.
- That EPA develop and describe alternative control strategies for HAPs that may require regulation under section 112.
- If appropriate, and necessary, the EPA is to proceed with rule-making activities to control HAP emissions from electric utility steam-generating units.

In this study, the EPA is required to develop and describe alternative control strategies for HAP emissions from electric utilities that might warrant regulation. The Administrator must regulate electric utility steam-generating units if such regulation is found to be appropriate and necessary after considering the results of the EPA study.

When the study began, only a small amount of reliable data on HAP emissions from electric steam-generating units was available; most of the new data did not become available until early in 1994. Because of the lack of data, the submission of EPA's study was delayed until November 1995. This has been recently revised to some time in 1996.

The EPA study specifically addresses the impact of pollution controls mandated by other sections of the Act, determines which HAPs are present in utility unit emissions, and estimates the risk to human health from the emissions of these HAPs. The details of the study are discussed in the sections below.

Overview and Approach of Electric Utility HAP Study. The goal of EPA's study was to determine if HAP emissions from electric utility industry present a health hazard to humans. The approach

taken in this study estimates the human health risks associated with direct exposure to HAP emissions from each utility unit. Human health risks are also examined for indirect exposure to, and long range transport of, selected HAP emissions from model plants.

The EPA report is a result of the work of governmental and non governmental personnel. Emissions testing, health risk modeling, and emissions estimation issues were discussed among numerous branches of EPA and among representatives of industry, the Electric Power Research Institute (EPRI), and the Department of Energy (DOE). In particular, as previously mentioned, the EPRI, the DOE, and the EPA coordinated their utility emissions testing to cover more plant configurations and obtain as much information as possible for the human health hazard and risk assessment. Information on the magnitude, control, and human health risks of mercury emissions was shared by those within and outside the EPA. The EPA report was reviewed by scientific experts within and outside the Agency to assure that the data and methodologies utilized were most sound.

It is important to note that the health aspects of the utility HAP emissions are judged after the Air Toxic provisions of Title III are applied to all other industries. Also, the health aspects of the utility HAP emissions are judged after other titles of the CAAA are applied to electric utilities, such as Title IV, Acid Rain. This allows the beneficial aspects of flue gas cleaning, such as wet SO₂ scrubbers, to help reduce utility HAP emissions as a collateral benefit at little or no incremental cost. That is, the electric utilities are judged only after all other industries are in compliance with Title III and the electric utilities are in compliance with Title IV. Thus, clean up of utility HAP emissions are considered as a final incremental measure. For these reasons, the EPA study focuses on projected electric power industry emissions in the year 2010.

Figure 4-10 shows the fossil fuel mix used by electric power utilities in 1990 and projected use in 2010. In each case, coal dominates at 81% of fuel usage, with oil decreasing from 6% to 2% and natural gas increasing from 13% to 17% between 1990 and 2010. Figure 4-11 shows total fossil fuel usage increasing from 21.3 Quads (10¹⁵ Btus) to 28.0 Quads in the same time period.

EPA Health Hazard Risk Assessment. Section 112 (n)(1)(A) of the 1990 Clean air Act Amendments requires the EPA to study the hazards to public health reasonably anticipated to occur as a result of hazardous air pollutant (HAP) emissions by electric utility steam generating

units (utilities) after imposition of the requirements of the 1990 Amendments. To fulfill this mandate, the EPA has conducted its health risk assessment.

The EPA evaluated the potential hazards and risk for the year 1990 and for the year 2010. The year 1990 was chosen as the base case since this is the latest year that site specific data were available from the Utility Data Institute (UDI) database. The 2010 year scenario was also assessed to meet the Congressional mandate to study the hazards "after imposition of the requirements of this Act."

Potential hazards and risks were evaluated for direct inhalation and indirect exposure pathways (i.e., multi-pathway exposure). The assessment includes both qualitative and quantitative information about hazards and risks. For HAPs, exposure pathways were sufficient; qualitative and quantitative estimates of risk were developed. However, where data were insufficient to calculate quantitative estimates of risk, EPA attempted to provide qualitative descriptions of potential hazards.

A significant portion of the analysis conducted by EPA focuses on direct inhalation risks due to utility emissions within a 50 km radius of each facility. The analysis of long-range transport or regional analysis and multi-pathway risk assessment were limited, mostly qualitative, and only considered a few pollutants. EPA emphasizes that direct inhalation exposure within 50 km is the most important route of exposure, but the assessment is more a reflection of the availability of resources and time available to conduct the assessment. For some of the HAPs emitted from utilities (e.g., mercury and dioxins), indirect exposure through ingestion is likely to be the dominant route of human exposure to these pollutants (14).

The estimates of exposure and risks presented by EPA in the (draft) report to Congress are incrementally increased exposures and risks due to utility emissions only. For the most part, EPA's assessment does not consider exposure to emissions from other sources, and does not consider background levels of pollution in the environment.

In conducting the risk assessment, the EPA employed a methodical system of quantitative and qualitative analytical procedures. The EPA defines risk assessment as "a multidisciplinary evaluation of factual information as the basis for estimating and evaluating the potential effects that individuals or populations may experience as a result of exposure to hazardous substances."

The assessment process follows a series of guidelines from the EPA, Risk Assessment Council, National Academy of Sciences, Science Policy Council, and others.

The EPA recognizes that the numerous assumptions and default values used in the analysis can either overestimate risks or underestimate risks. The EPA considers the results to be conservative estimates of risks due to direct inhalation exposure of utility emissions within 50 km of the utility.

The inventory of utilities modeled included all coal-, oil- and gas-fired plants that have at least one boiler of 25 MW or more: 426 coal-fired plants, 137 oil-fired plants, and 267 gas-fired plants. The EPA based their results on 12 HAPs (plus radionuclides) that appear to be of the greatest public health concern. The 12 HAPs contain eight carcinogens and four noncarcinogens. These are shown in Table 4-4 for coal-, oil- and gas-fired utility boilers. The six carcinogens that are the major contributors to the total cancer risk from electric utilities are arsenic, beryllium, cadmium, chromium, dioxins/furans, and nickel (11).

Inhalation Risks from Electric Utilities. A total of 426 coal-fired plants were modeled using 1990 emissions and population data. The results are based on the Maximally Exposed Individual (MEI) principle. The summary of the risks associated with HAP emissions was shown in Table 4-4. No coal-fired plants had a inhalation cancer risk of more than one in 100,000 or more persons (10^{-5}) for any single HAP. Arsenic and chromium were the major contributors to direct inhalation cancer risk from coal-fired boilers.

A total of 137 oil-fired plants were evaluated. The highest risk emission was nickel, followed by arsenic. There were 79 oil-fired plants with risks exceeding one in 10,000,000 due to nickel exposures and 22 plants that exceeded this level on arsenic. The EPA notes that there is considerable uncertainty regarding the species distribution within the nickel emissions. The speciation of nickel greatly influences its carcinogenicity. EPA also notes that they have chosen to use very conservative values in their assessment.

Risks were also estimated for 267 gas-fired plants. Gas-fired plants were determined to present negligible risks from HAP emissions. This is because eleven of the twelve HAPs considered by the EPA originate solely from the mineral matter contained in the ash precursors of the coal and oil fuels.

Mercury Compounds. Mercury compounds received special attention in the 1990 environmental legislation. Mercury is addressed in Title III (and relatedly Title V) CAAA of 1990 requirements, as well as, in numerous other increasingly stringent environmental regulations (e.g., expansion of the Clean Water Act Amendments and Great Lakes Initiatives, etc.).

Mercury has a very high environmental persistence, has a tendency to bioaccumulate, and is toxic via the oral exposure route. Mercury causes noncancer effects at relatively low concentrations.

Emissions of mercury (Hg) from coal- and oil-fired electric utilities constitutes approximately 23% of U.S. anthropogenic emissions of Hg. The utilities combined emission of mercury is estimated at 55 tons per year by the EPA (14)..

The concern for mercury pollution is illustrated by numerous fish advisories and by exceedences of water quality standards. Mercury has been identified as a "pollutant of concern" in EPA report to Congress, "Deposition of Air Pollutants into the Great Lakes Waters". Mercury is one of seven pollutants that require source accounting for 90 percent of aggregate emissions of each HAP to be subject to emissions standards to be promulgated by November 2000.

Since mercury volatilizes at a low temperature (183 °F), mercury emissions from utility boilers are entirely vapor phase. This makes the collection of mercury by the plant's flue gas cleaning system quite difficult. Most other HAPs reside in the solid particulate matter that is collected with high efficiency (typically 95-99.9%). The vaporous mercury compounds generally pass through the particulate control system. Even wet scrubber systems for gaseous SO₂ only collect a small fraction of the he water soluble mercury compounds.

Mercury pollutants occur in several species. One form is elemental mercury (Hg⁰) which accounts for typically, 20-60% of mercury emissions from coal. The other common form is oxidized mercury (Hg⁺²), which accounts for typically, 40-80% of mercury emissions from coal. This form is exemplified by compounds such as mercury chloride. Another complexity in tracking mercury emissions is the complex atmospheric transformation pathways that occur, as shown in Figure 4-12.

The most potent mercury compound commonly found in the environment is methylmercury. Methylmercury has been found to affect the central nervous system. Early symptoms to chronic

exposure to low levels of methylmercury are prickling on the skin, blurred vision, and malaise. At higher doses, deafness, speech difficulties, and constriction of the visual field are seen. Infants born to women who ingested high levels of methylmercury (usually from fish) exhibited central nervous system effects, such as, mental retardation, ataxia, deafness, blindness and cerebral palsy.

Fish mercury levels in fish are the single greatest concern with regard to mercury pollution. Because of the extended transport range of vaporous mercury compounds, fish in lakes seemingly far removed from anthropogenic sources have been found to have mercury levels of concern to human health. Mercury levels in U.S. fish vary greatly, often showing little correlation to proximity to mercury emissions sources.

Mercury Deposition from Electric Utilities. EPA's modeling estimates of the long-range transport and deposition of atmospheric mercury emissions from fossil-fueled electric utility boilers and from all other anthropogenic sources in the continental U.S. has determined that the electric utilities contribute about 20% (14.3 metric tons) total deposition. The EPA's confidence in these figures is, however, low because of the previously discussed compounding uncertainties regarding the chemical and physical forms of mercury emissions and the atmospheric transformation of mercury forms. This uncertainty and low confidence level of the EPA in their own findings is critical to the expected recommendations to Congress. This point will be discussed further in the Conclusions section of this report.

The EPA study has concluded (15) that the highest annual rate of mercury deposition occurs in:

- a. The southeastern Great Lakes and the Ohio River Valley.
- b. Most of central and western Pennsylvania.
- c. The urban corridor from Washington, D.C. to New York City.
- d. In the vicinity of many larger cities in the eastern U.S. and in numerous isolated locations near coal-fired utilities.

In these areas, electric utilities account for 20-40% of the mercury deposited.

Conclusions, Findings and Recommendations of the EPA Report. As previously discussed, the EPA's Report to Congress on Air Toxics was originally due on November 15, 1993. Because of the inadequacy of accurate power plant emissions data on the minute concentrations of HAPs, the EPA negotiated a series of delays up to November 15, 1995. The Conclusions, Findings and Recommendations were to have been circulated for Peer review in September of 1995 (15). In October, 1995, the EPA suddenly (but based on historical performance, not surprisingly) delayed these sections to at least January 1996. This draft material is not available at this writing for inclusion in this report.

5.0 Conclusions

There currently appears to be little scientific evidence to justify regulation of HAPs from the electric power generation industry. Compared to motor vehicles, the chemical industry and several other sources, the HAPs emissions from the electric power industry are quite low. Leonard Levin of EPRI (12) uses a pie chart that shows the total HAPs emissions in the U.S., with the electric industry's contribution below 1%.

Although the EPA has yet to publish their conclusions for The Report to Congress on Air Toxics, it is possible to draw tentative conclusions, based on the authors' recent personal meetings and/or discussions with air toxics experts in industry and government. The conclusions of these experts and of other cognesi in the industry are: (1) the levels of organic air toxics are below any reasonable control limits; and (2) nonvolatile inorganic air toxics (e.g., chromium, arsenic, lead, etc.) are effectively collected (@ >98%) by any modern air pollution control equipment (e.g., ESPs) to warrant their regulation.

Even though the Mercury Emission Study mandated under the Act [Section 112 (n)(1) (A)] showed no serious health effects from mercury in the environment (14), there is considerable pressure from environmental groups to impose mercury limits on power plants. " As one EPA staffer put it recently, mercury is a 'hot button'." (16) Power plants are the number three source of mercury in the environment, accounting for approximately 20 percent of mercury emissions. Air toxics experts feel that there is a definite uncertainty over mercury species being emitted. Because of the continuing uncertainty over mercury quantities being emitted and their speciation, as well as a lack of commercial and cost-effective mercury control technology, this review concludes that mercury emissions will not be regulated at this time. Further studies on the above topics will be needed prior to development of a clear view of the health and environmental risks posed by electric utility mercury emissions.

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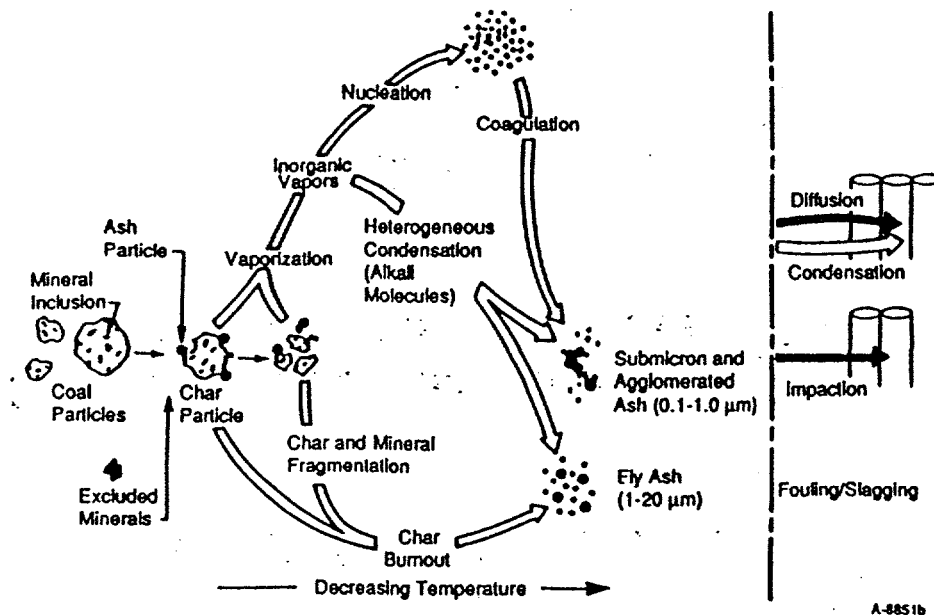
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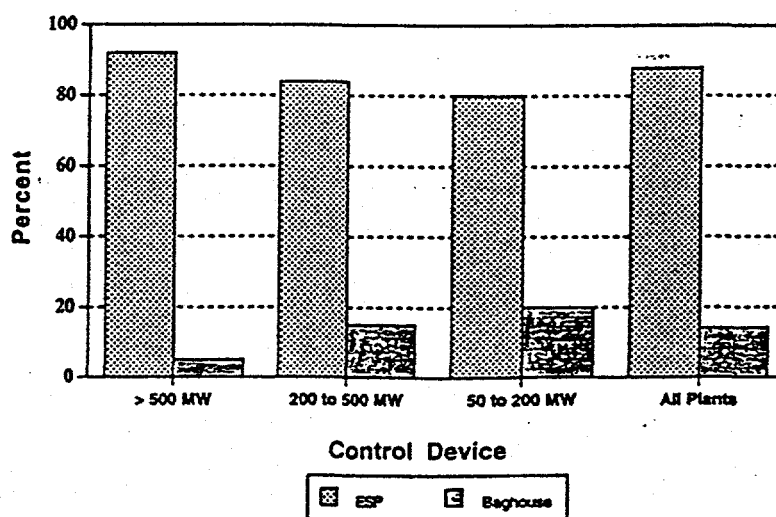
Tables & Figures



A-4851b

- Ash formation and ash deposition clearly depend upon MINERALOGY of coal
 - Size of minerals
 - Composition of minerals
 - Elemental form
 - Combustion behavior of individual minerals

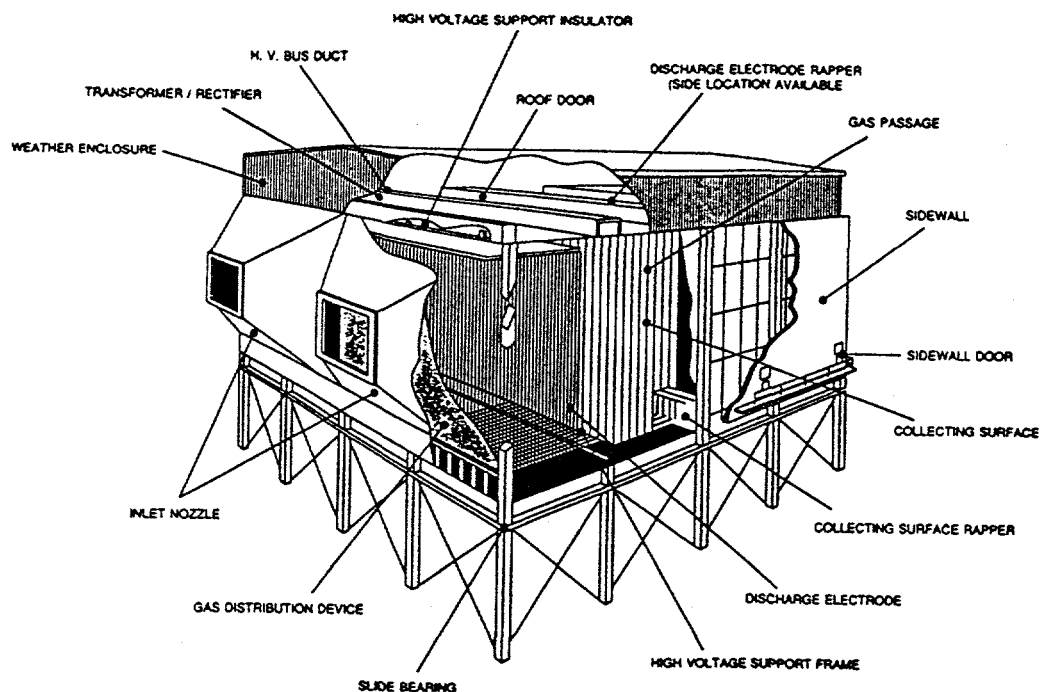
Figure 4-1
Ash Transformation Pathways (Ref. 18)



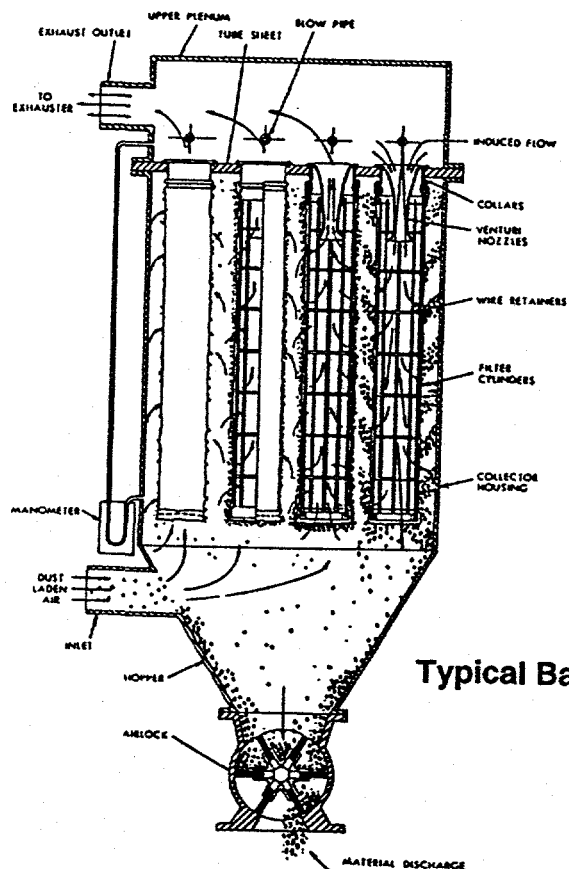
US Coal - Fired Utilities (Ref. 17)
Installed Particulate Controls †

Source: EEI Environmental Database, 1991

Figure 4-2



Typical Electrostatic Precipitator (ESP) (Ref. 19)



Typical Baghouse

**Figure 4-3
Schematics of ESP and Baghouse (Ref. 19)**

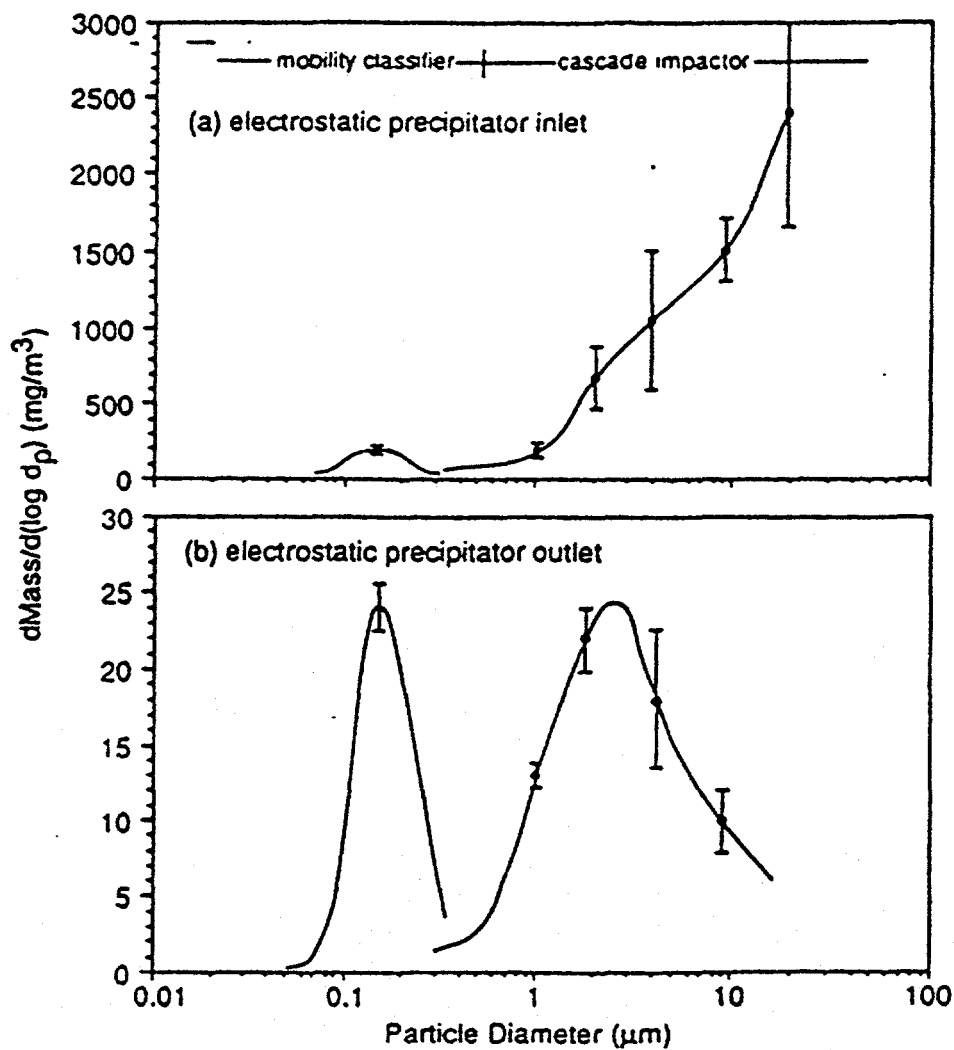


Figure 4-4
Comparison of submicron and supermicron particulate
collection efficiency through a high efficiency ESP (Ref. 20)

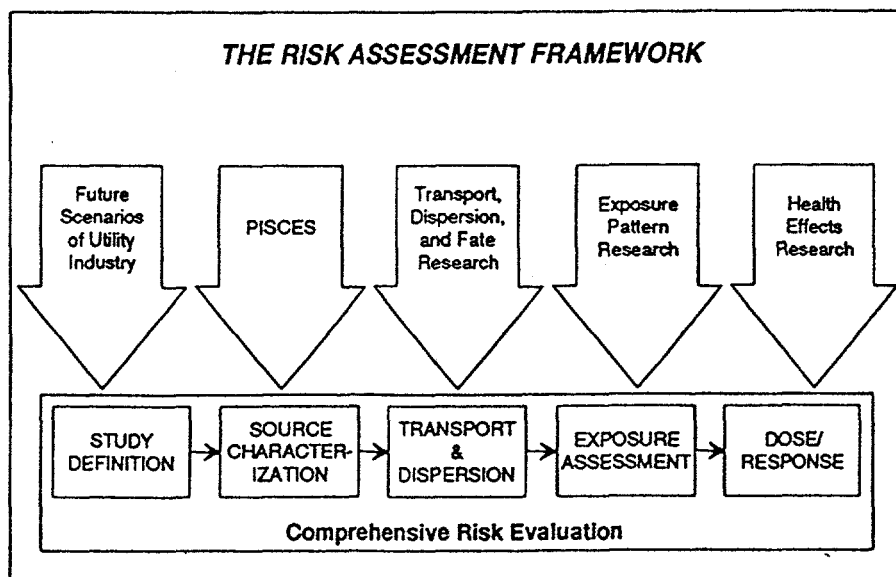


Figure 4-5
EPRI Risk assessment Framework (Ref. 12)

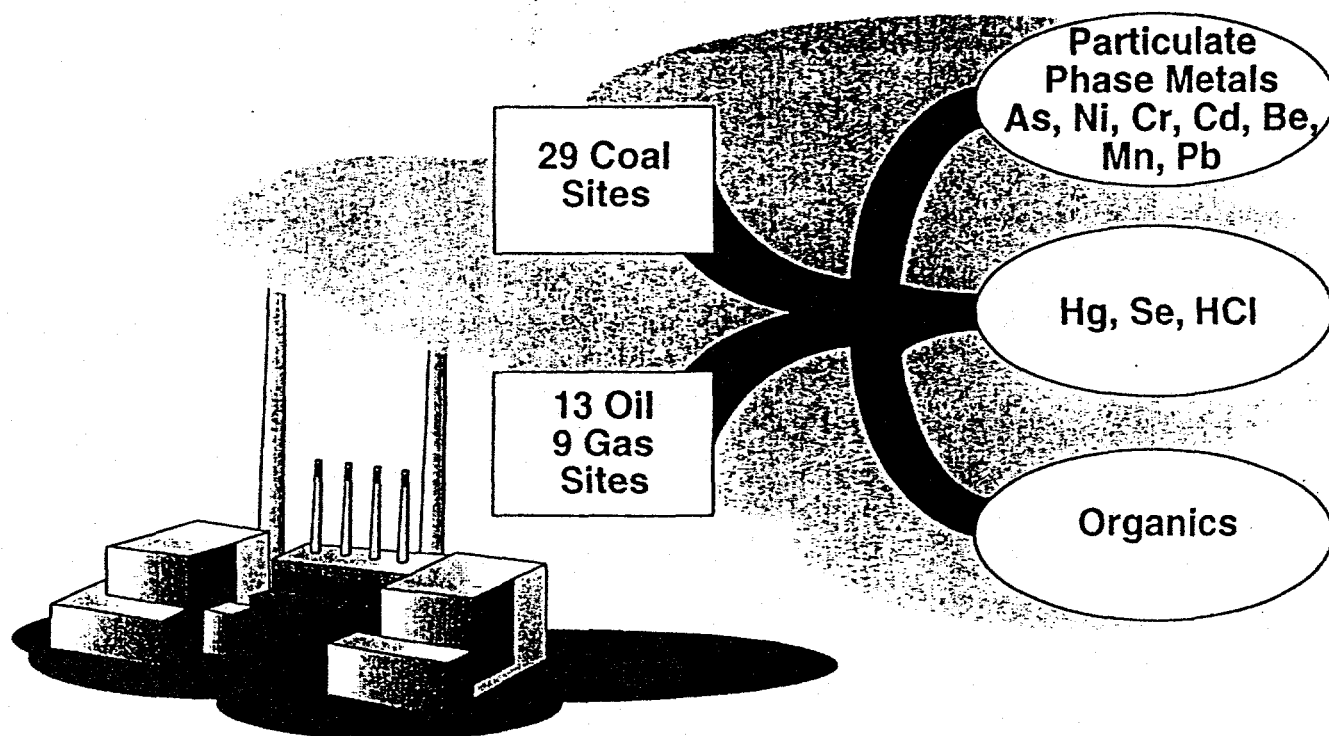


Figure 4-6
Distribution of Fuel Type at EPRI Test Sites (Ref. 13)

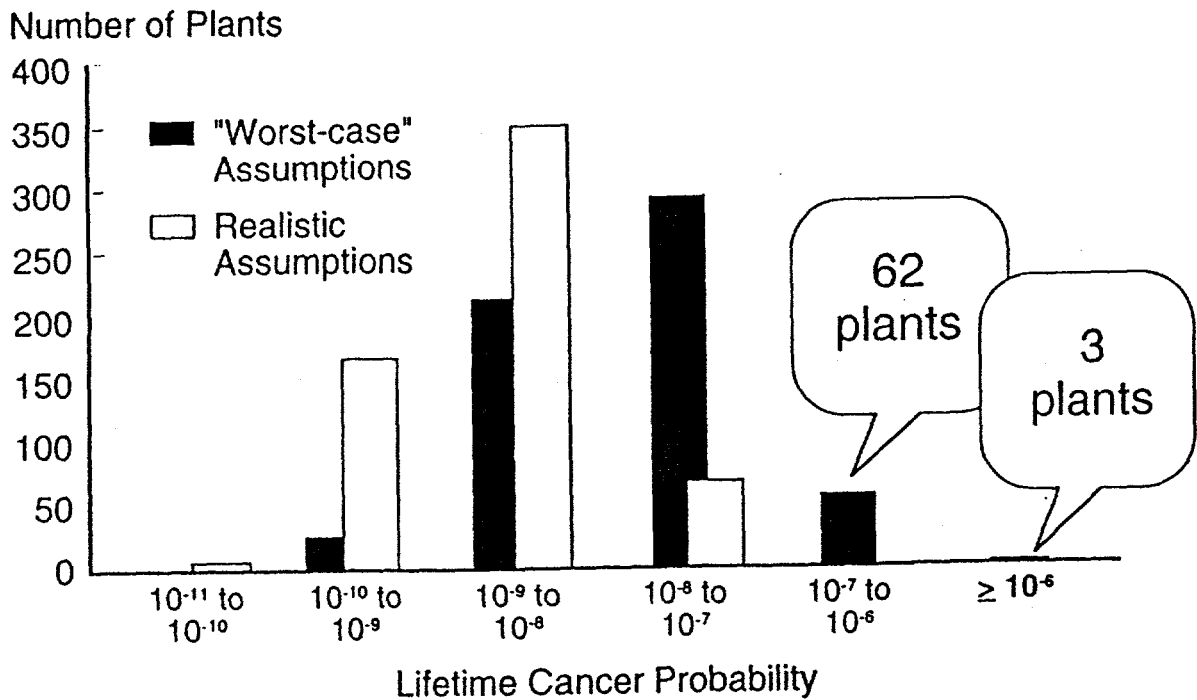


Figure 4-7
Distribution of inhalation carcinogenic risk, reasonable exposure vs. maximal exposure (Ref. 13)

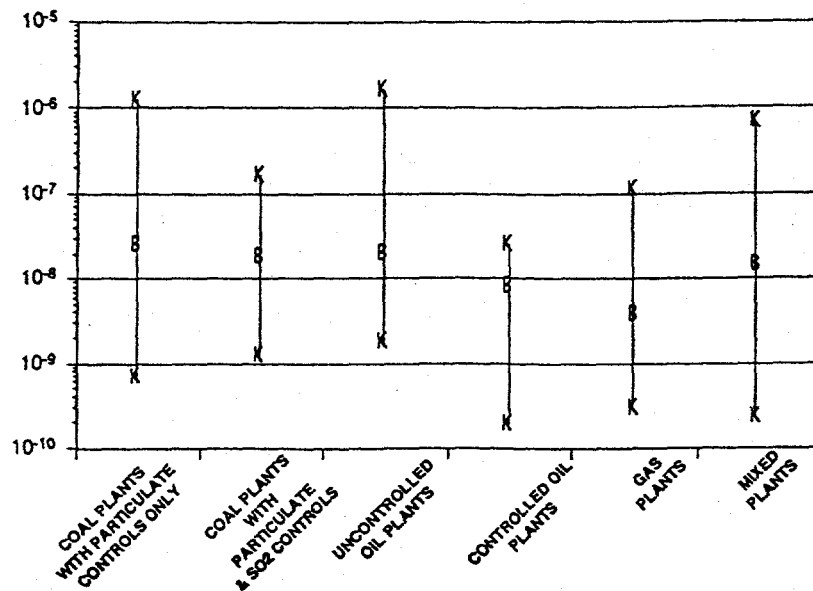


Figure 4-8
Range of inhalation risk, maximally exposed individual, by power plant group (Ref. 12)

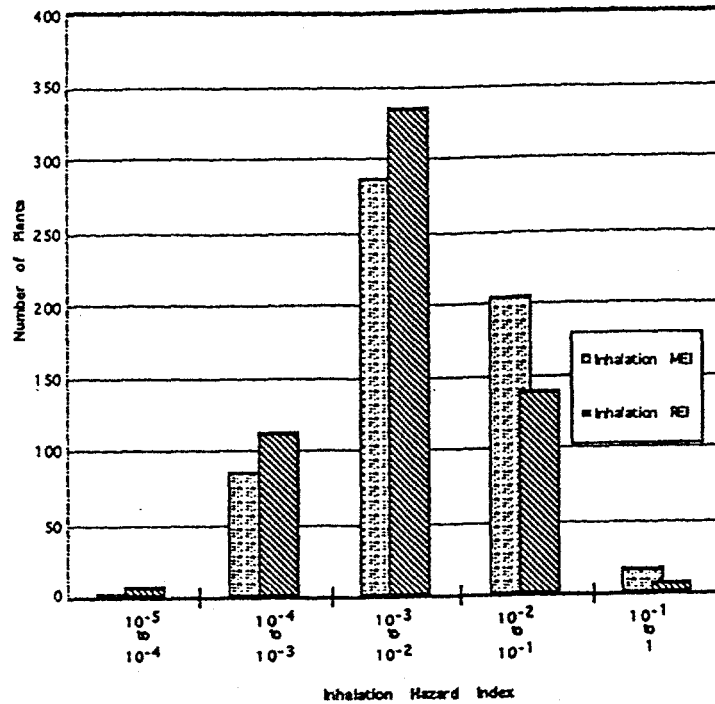


Figure 4-9
Distribution of inhalation hazard (non cancer) index
reasonable exposure vs. maximal exposure (Ref. 12)

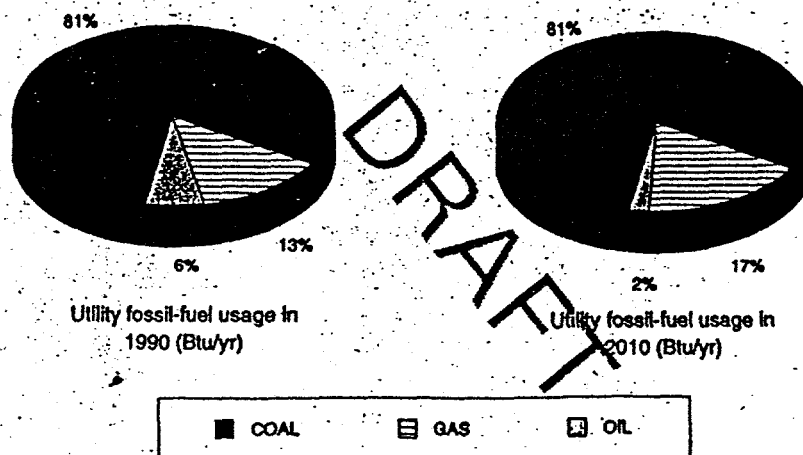


Figure 4-10
Fossil-fuel use in the electric utility industry by fuel type
in 1990 and projections for the year 2010 (Ref. 15)

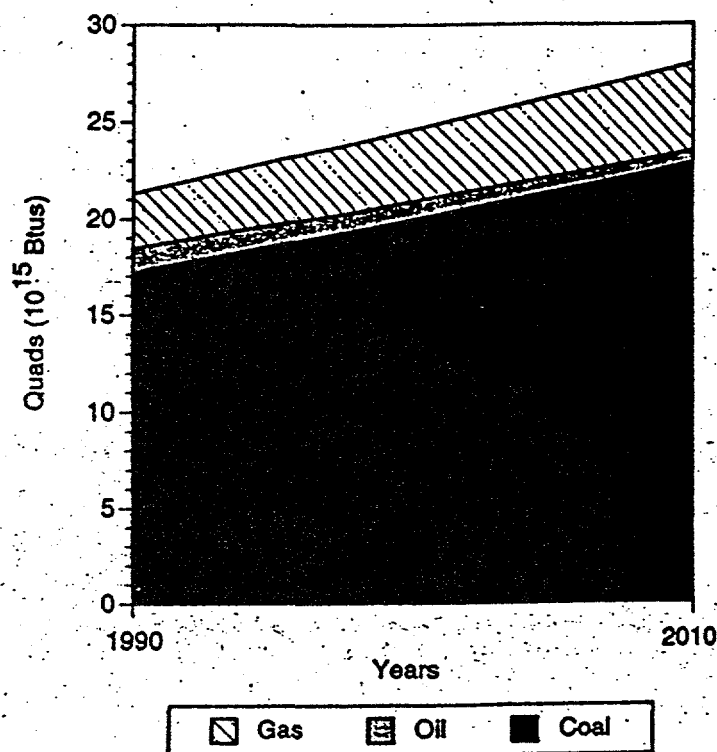


Figure 4-11
Projected use of fuels by 2010
for electric utility industry (Ref. 15)

Reaction	Equilibrium or Reaction Rate Parameter ^(a)
1. $\text{Hg}^0(\text{g}) + \text{O}_3(\text{g}) \longrightarrow \text{Hg}(\text{II})(\text{g})$	$< 8 \times 10^{-19} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$
2. $\text{Hg}^0(\text{g}) + \text{Cl}_2(\text{g}) \longrightarrow \text{HgCl}_2(\text{g})$	$\leq 4.1 \times 10^{-16} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$
3. $\text{Hg}^0(\text{g}) + \text{H}_2\text{O}_2(\text{g}) \rightarrow \text{Hg}(\text{OH})_2(\text{g})$	$\leq 4.1 \times 10^{-16} \text{ cm}^3 \text{ molec}^{-1} \text{ s}^{-1}$
4. $\text{Hg}_2^{2+} \rightleftharpoons \text{Hg}^0(\text{aq}) + \text{Hg}^{2+}$	$2.9 \times 10^9 \text{ M}$
5. $\text{Hg}^{2+} + \text{SO}_3^{2-} \rightleftharpoons \text{HgSO}_3(\text{aq})$	$5.0 \times 10^{12} \text{ M}^{-1}$
6. $\text{HgSO}_3(\text{aq}) + \text{SO}_3^{2-} \rightleftharpoons \text{Hg}(\text{SO}_3)_2^{2-}$	$2.5 \times 10^{11} \text{ M}^{-1}$
7. $\text{Hg}(\text{SO}_3)_2^{2-} \longrightarrow \text{Hg}^0(\text{aq})$	$1 \times 10^{-4} \text{ s}^{-1}$
8. $\text{HgSO}_3(\text{aq}) \longrightarrow \text{Hg}^0(\text{aq}) + \text{SO}_3^{2-}$	0.6 s^{-1}
9. $\text{Hg}^0(\text{aq}) + \text{O}_3(\text{aq}) \longrightarrow \text{Hg}(\text{II})(\text{aq}) + \text{O}_2(\text{aq})$	$4.7 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$
10. $\text{Hg}(\text{OH})_2(\text{aq}) \rightleftharpoons \text{Hg}^{2+} + 2 \text{ OH}^-$	10^{-22} M^2
11. $\text{HgCl}_2(\text{aq}) \rightleftharpoons \text{Hg}^{2+} + 2 \text{ Cl}^-$	10^{-14} M^2
12. $\text{Hg}^*(\text{g}) \rightleftharpoons \text{Hg}^0(\text{aq})$	0.11 M/atm
13. $\text{HgCl}_2(\text{g}) \rightleftharpoons \text{HgCl}_2(\text{aq})$	$1.4 \times 10^6 \text{ M/atm}$
14. $\text{Hg}(\text{OH})_2(\text{g}) \rightleftharpoons \text{Hg}(\text{OH})_2(\text{aq})$	$1.2 \times 10^4 \text{ M/atm}$
(a) At 25°C except reaction (1) (22°C) and reaction (12) (20°C)	

Figure 4-12
Atmospheric Chemical Kinetic Mechanisms of Mercury (Ref. 20)

Site	Contractor	Power Plant	Operator	Size(MW)	Coal	SO ₂	NO _x	Part
1	SRI	Springerville	Tucson Elec Company	360	Sub	SDA	OFA	BH
2	SRI	Bailly	NIPSCO	528	Bit	Limestone Scrubber	None	ESP
3	EER	Cardinal	Ohio Power Company	615	Bit	None	None	ESP
4	Weston	Baldwin	Illinois Power	570	Bit	None	None	ESP
5	Weston	Clay Boswell	Minnesota Power	69	Sub	None	None	BH
6	Radian	Yates	Georgia Power	100	Bit	Limestone Scrubber	None	ESP
7	Battelle	Niles	Ohio Edison	100	Bit	None	None	ESP
8	Battelle	SNOX	ABB	35	Bit	WSA	SCR	BH
9	Battelle	Coal Creek	Cooperative Power	550	Lig	Lime Scrubber	OFA	ESP

Contractors

SRI - Southern Research Institute
EER - Energy and Environmental Research Corporation

Operators

ABB - Asea Bavaria Brown
NIPSCO - Northern Indiana Public Service Company

Pollution Control Technologies

OFA - Over-Fire Air
BH - Baghouse
SDA - Spray Dryer Absorber
ESP - Electrostatic Precipitator
SNOX - Wet Gas Sulfuric Acid-Selective Reduction of NO_x
WSA - Wet Sulfuric Acid Selective Catalytic Converter
SCR - Selective Catalytic Reduction

Table 4-1
DOE Phase 1 power plant descriptions (Ref. 9)

Trace Metals (lbs/10 ¹² Btu)			Trace Organics (lbs/10 ¹² Btu)		
Metal	DOE	Ref. 13	Organic	DOE	Ref. 13
Antimony	<0.1 - 2.4	NA	Benzene	3.4 - 170	NA
Arsenic	0.1 - 42	<1 - 860	Toluene	2.0 - 24	NA
Beryllium	<0.1 - 1.4	<1 - 32	Naphthalene	<0.1 - 1.9	a/
Cadmium	<0.1 - 3.0	1 - 490	Anthracene	(3.0 - 20) 10 ⁻³	a/
Chromium	<0.1 - 51	10 - 5000	Phenanthrene	(2.0 - 31) 10 ⁻²	a/
Cobalt	<0.1 - 6.8	NA	Pyrene	(3.0 - 40) 10 ⁻³	a/
Lead	0.6 - 29	NA	Benzo(a)pyrene	(2.0 - 12) 10 ⁻⁴	a/
Manganese	1.1 - 22	30 - 2400	Formaldehyde	1.4 - 57	63 - 2100
Mercury	0.5 - 14	1 - 22	2-Butanone	3.7 - 16	NA
Nickel	0.3 - 40	1 - 2500	2,3,7,8-TCDD	(8.1 - 25) 10 ⁻⁷	NA
Selenium	<0.1 - 130	NA	2,3,7,8-TCDF	(6.6 - 9.9) 10 ⁻⁷	NA

a/ The literature data are classified as Polycyclic Organic Matter and range from 0.03 to 565 lbs/10¹² Btu.

Table 4-2
Emissions factor ranges for trace metal (Ref. 9)
and selected organic HAPs

Exposure Measure	MEI (Maximally Exposed Individual)	REI (Reasonably Exposed Individual)
• Exposure Time	70 years	Average amount of time living in one area (approx. 19 years)
• Power Plant Replacement	none	After 55 years of operation, unit is replaced with similar unit that meets 1994 NSPS for particulates (0.03 lb/10 ⁶ Btu)
• Concentrations	The highest outdoor concentration due to plant emissions in a populated area within 50 km	The highest outdoor and indoor concentrations due to plant emissions in a populated area within 50 km (indoor concs. approx. 60% of outdoor concs. for partic. matter)
• Time spent outdoors	24 hrs/day	Fraction of day based on activity pattern data
• Breathing Rate	20 m ³ /day	Varying by activity; age-weighted
• Susceptibility to health effects	to average	average

Table 4-3
EPRI Exposure Assumptions (Ref. 12)

Summary of Risk by HAP: Coal-fired Power Plants.

Pollutant	Carcinogens					Noncarcinogen
	MEI	Population MIR > 10 ⁻⁷	# Plants MIR > 10 ⁻⁷	Population MIR > 10 ⁻⁶	# Plants MIR > 10 ⁻⁶	HQ _{max}
Arsenic	3x10 ⁻⁶	1.7M	42	2,370	2	NA
Beryllium	3x10 ⁻⁷	1,280	2	0	0	NA
Cadmium	2x10 ⁻⁷	107	1	0	0	NA
Chromium*	2x10 ⁻⁶	80,500	10	107	1	NA
Dioxin/Furans	5x10 ⁻⁸	0	0	0	0	NA
Hydrogen Chloride	NA	NA	NA	NA	NA	0.12
Lead	NA	NA	NA	NA	NA	0.001
Manganese	NA	NA	NA	NA	NA	0.046
Mercury	NA	NA	NA	0	0	0.002
Nickel ^b	7x10 ⁻⁷	5,100	3	0	0	NA
n-Nitrosodimethylamine	8x10 ⁻⁷	9,150	0	0	0	NA
Total	4x10 ⁻⁶	NA	13	NA	2	NA

MEI = Maximum exposed individual, which is calculated using the highest concentration. An individual may or may not be exposed at that point. This value may be greater than the MIR, which is calculated at the centroid of a census block.

MIR = Maximum individual risk is the highest risk identified at the centroid of a census tract to which a population is assigned.

NA = Not available.

HQ = Hazard quotient, the ratio of exposure concentration to the Reference Concentration (RfC). HQ values below 1 are not expected to result in adverse effects.

Total = Total MEI and Total MIR are the sum of the MIR and MEI for individual HAPs within a plant. The total HQ (=HI) is the sum of the HQs within a plant.

*Assumes that 11% of total chromium emitted is hexavalent chromium, the species of chromium responsible for carcinogenic potential. Trivalent chromium which would also be present is not thought to have carcinogenic potential.

^bThe nickel emitted is a mixture of various nickel compounds such as soluble nickel. This analysis assumes that all nickel emitted has the same carcinogenic potency as nickel subsulfide.

Table 4-4
EPA Summary of Risk by HAP (Ref. 15)
(Continued on next page)

Summary of Risk by HAP: Oil-Fired Power Plants

Pollutant	Carcinogens					Noncarcinogen
	MEI	Population MIR > 10 ⁻⁷	# Plants MIR > 10 ⁻⁷	Population MIR > 10 ⁻⁶	# Plants MIR > 10 ⁻⁶	HQ _{max}
Arsenic	1 x 10 ⁻⁶	2.1M	22	2370	2	NA
Beryllium	8x10 ⁻⁷	2,280	2	0	0	NA
Cadmium	2x10 ⁻⁶	3,040	2	45	1	NA
Chromium ^a	5x10 ⁻⁶	257,000	10	2,280	1	NA
Dioxin/Furans	1 x 10 ⁻⁷	45	1	0	0	NA
Hydrogen Chloride	NA	NA	NA	0	0	0.0055
Lead	NA	NA	NA	0	0	0.0004
Manganese	NA	NA	NA	0	0	0.037
Mercury	NA	NA	NA	0	0	0.0005
Nickel ^b	1 x 10 ⁻⁴	73M	79	1.6M	20	NA
Total	1 x 10 ⁻⁴	NA	NA	NA	22	NA

- MEI = Maximum exposed individual, which is calculated using the highest concentration. An individual may or may not be exposed at that point. This value may be greater than the MIR, which is calculated at the centroid of a census block.
- MIR = Maximum individual risk is the highest risk identified at the centroid of a census tract to which a population is assigned.
- NA = Not available.
- HQ = Hazard quotient, which is the ratio of exposure concentration to the Reference Concentration (RfC). HQ values below 1 are not expected to result in adverse effects.
- Total = Total MEI and Total MIR are the sum of the MIR and MEI for individual HAPs within a plant. The total HQ (=HI) is the sum of the HQs within a plant.

^aAssumes that 18% of total chromium emitted is hexavalent chromium, the species of chromium responsible for carcinogenic potential. Trivalent chromium, which would also be present, is not thought to have carcinogenic potential.

^bThis analysis conservatively assumes that all nickel emitted from electric utilities has the same carcinogenic potency as nickel subsulfide (the highest potency of nickel compounds tested). However, the nickel emitted is a mixture of various nickel compounds such as soluble nickel. Emissions tests have found nickel subsulfide to be present as less than 10% of total nickel emitted. Most nickel compounds are assumed to have carcinogenic potential though the potency is not known. If the relative potency (URE) of the mixture of nickel compounds emitted from oil-fired utilities was 50% of nickel subsulfide, about 23 million persons would be exposed at an MIR > 10⁻⁷, and 100,000 at an MIR > 10⁻⁶. If the URE were 20% of nickel subsulfide, about 7.5 million persons would be exposed at an MIR > 10⁻⁷, and 9,930 at an MIR > 10⁻⁶.

Summary of Risk by HAP: Gas-Fired Power Plants

Pollutant	Carcinogens					Noncarcinogen
	MEI	Population MIR > 10 ⁻⁷	# Plants MIR > 10 ⁻⁷	Population MIR > 10 ⁻⁶	# Plants MIR > 10 ⁻⁶	HQ _{max}
Arsenic	2x10 ⁻⁷	0	0	0	0	NA
Lead	NA	NA	NA	NA	NA	1.32x10 ⁻⁷
Mercury	NA	NA	NA	NA	NA	6.6x10 ⁻⁷
Nickel ^a	2x10 ⁻⁷	23	1	0	0	NA

- MEI = Maximum exposed individual, which is calculated using the highest concentration. An individual may or may not be exposed at that point. This value may be greater than the MIR, which is calculated at the centroid of a census block.
- MIR = Maximum individual risk is the highest risk identified at the centroid of a census tract to which a population is assigned.
- NA = Not available.
- HQ = Hazard quotient, which is the ratio of exposure concentration to the Reference Concentration (RfC). HQ values below 1 are not expected to result in adverse effects.

^aThe nickel emitted is a mixture of various nickel compounds such as soluble nickel. This analysis assumes that all nickel emitted has the same carcinogenic potency as nickel subsulfide.

Table 4-4 (Continued)
EPA Summary of Risk by HAP (Ref. 15)